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Metal Progress

December 1947

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Metal Progress; Page 962

The Use of Gaseous Oxygen in Metallurgical Processes

By **George V. Slottman**
Manager, Technical Sales Division
and P. M. Hulme
Metallurgical Engineer
Air Reduction Co., Inc., New York City

Use of oxygen in metallurgical processes has been the subject of theoretical speculation for half a century, mostly in terms of tonnage oxygen at a very low cost and in large quantity, and practical applications have been hampered by such ideas regarding economics. Recent experience of the steel industry with the injection of moderate amounts of oxygen into openhearth baths has shown that it can be used to advantage in "medicinal" doses to regulate temperature and control the speed of reaction. Similar opportunities probably exist in other metal refining operations.

THE THEORETICAL advantages of using gaseous oxygen in place of air or metallic oxides in the oxidation reactions common to metallurgical processes have long been recognized. The patent literature on this subject dates back more than 50 years. In 1924, in a symposium held by the American Institute of Mining Engineers under the auspices of the U. S. Bureau of Mines, many of the common metallurgical operations including those in the blast furnace, the bessemer converter and the openhearth were analyzed, and favorable conclusions were drawn regarding the advantages of using oxygen if and when available at a cost of $3 per ton. Since oxygen at that time was being produced only in limited quantities and was available only in high pressure cylinders of small capacity and at a cost of some $300 per ton, the application to actual metal production seemed merely an interesting theoretical speculation. As a result, metallurgical thinking with respect to oxygen bogged down in the wide spread between the then actual and the theoretically desirable cost. Since then the use of oxygen has been generally dismissed with the simple phrase, "Too expensive even to consider."

Since 1924, when oxygen was being used principally in small quantities in maintenance tools for welding and cutting, the development of broad new uses in production tools for fabricating metals and in conditioning of steel surfaces, coupled with improvements in its manufacturing processes, has made oxygen available in quantity today at very considerably less than its former cost. Thus, there is evidently a gap between the very large tonnage use of oxygen as a combustion aid in blast furnace and openhearth, and present-day applications of high-purity oxygen for cutting and conditioning steel. This "no man's land" offers a fertile field for metallurgical research. The purpose of this paper is to add force to such a conclusion by analyzing the results of a year's practical application of oxygen to the problems of openhearth steelmaking.

Tonnage Oxygen—To distinguish more clearly between *tonnage* oxygen and the medium-scale use of oxygen as now available, it may be considered that "tonnage oxygen" literally involves the application of oxygen by the ton, and regardless of the oxygen purity. Since the capital cost of oxygen producing equipment, per ton of output, increases rapidly with decreasing production, ton-

nage uses requiring oxygen of low cost must involve consumptions of the order of 100 to 3000 tons of oxygen *per day*. Such consumptions are typical of uses to aid combustion in blast furnace and openhearth. On the other hand, the wide uses of high-purity oxygen (which are the subject of the present article) are of the order of 10 to 1000 tons *per month*. They are definitely *not* in the tonnage oxygen class, in the above sense.

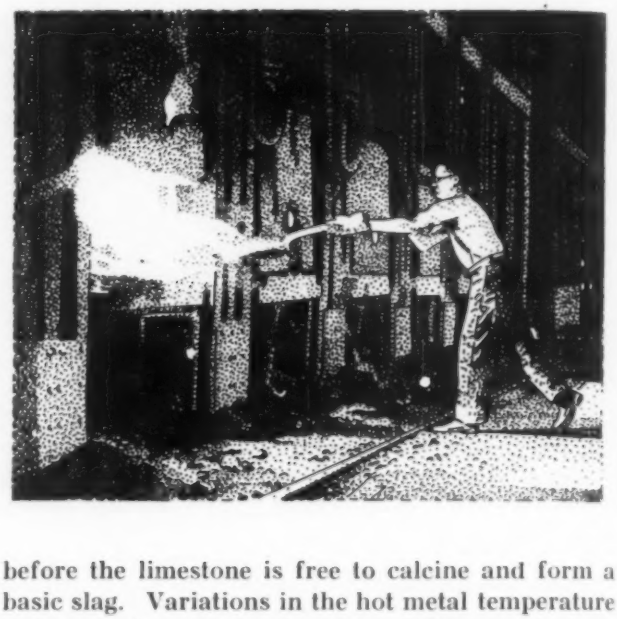
Generally speaking, in combustion reactions (and particularly where oxygen is being used not as a pure oxidant, but to enrich the combustion air) a tonnage oxygen application is indicated. Where oxygen is employed as an oxidizing agent to combine with minor chemical elements, the volume of oxygen required even in large-scale metallurgical operations is comparatively small, and a medium-scale use of the high-purity oxygen now commercially available is indicated. The past year's application of oxygen to openhearth practice emphasizes this distinction; the use of oxygen for accelerating fuel combustion is a tonnage use, requiring large volumes at costs below present prices for high-purity oxygen, whereas the use of oxygen for decarburization and for the direct heating of the bath, involving much smaller quantities, has been found economical at present costs of high-purity oxygen. (See, for example, the paper on "Direct Oxidation" given by E. B. Hughes before the A.I.M.E.'s Openhearth Conference held in Cincinnati in March 1947.) While production of tonnage oxygen is being actively engineered and the first plant to supply tonnage oxygen for metallurgical purposes is nearing completion at Johnstown, Pa., the many potential applications of the oxygen that is now available warrant further attention, in the light of these recent developments in openhearth practice.

Limiting Factors in Openhearth Practice

Steelmaking in the openhearth furnace is a slow and tedious process, and production rates in terms of tons per hour are low compared with the bessemer process. The principal causes of this, aside from the time required to charge and melt scrap, are

1. The low rate of heat transfer between the heating gases and the metal bath,
2. The endothermal nature of the oxidation reactions utilizing iron ore or scale, involved in the refining of steel, and
3. The variable nature of the charge, both as regards physical temperatures and chemical analysis.

In the normal scrap plus hot metal process, considerable time is required after hot metal has been added to melt the scrap resting on the hearth,



before the limestone is free to calcine and form a basic slag. Variations in the hot metal temperature and analysis result in disturbing differences in bath temperature and in slag volume, heat to heat. The use of ore as an oxidizing agent requires the absorption of considerable thermal energy to compensate for the strongly endothermal nature of the oxidation reactions. The rate of carbon and manganese elimination is therefore very low (0.3 to 0.5% *per hr.* as compared with 0.25% *per min.* in the bessemer). As the carbon content falls and the melting point of the steel rises, it becomes increasingly difficult to transfer heat from the flame to the bath, because there is a decreasing temperature differential between flame and metal, as well as a lowering coefficient of heat transfer as the bath becomes less active and exposes a smaller surface to the flame.

Oxygen is being used both experimentally and in production to accelerate these reactions which normally limit openhearth production rates. It is being applied to the hot metal to produce high-temperature iron of a constant and low-silicon content. Injected into the bath, either through an iron pipe immersed in the molten bath or through a water cooled nozzle blowing on the surface, it is being used to hasten the melting of scrap and the start of the lime boil. Elimination of carbon and manganese with oxygen, particularly in the low-carbon ranges, is becoming standard practice. Some work is being done for rapidly raising the bath to any desired temperature by the use of oxygen both with and without substances such as ferrosilicon.

Even at this early stage in the development, it is evident that a new tool is now available in steelmaking practice, which gives the openhearth operator a far greater control over bath temperature, activity and composition than heretofore.

Of particular interest is the fact that these uses have entailed only limited quantities of high-purity oxygen, far removed from tonnage oxygen concepts, and have resulted in very significant increases in the rates of the metallurgical reactions involved.

Control of Hot Metal

Molten blast furnace iron, for use as hot metal in openhearth steelmaking, should be low in silicon to reduce the slag volume to be handled, and should be as hot as possible to reduce the energy requirements of the refining processes. Since, in blast furnace practice, cold iron and low silicon are synonymous, a compromise between the desired silicon content and the metal temperature is made.

Table I — Effect of Oxygen Treatment on Silicon, Manganese and Temperature of Mixer Iron

Time (Min.)	Chemical Analysis					Temperature
	C	Mn	P	S	Si	
Test No. 1 (3 Tons)						
0	4.27	1.68	0.140	0.031	1.85	2532° F.
5.9	4.20	1.22	0.140	0.027	1.45	
8.9	4.15	0.94	0.140	0.027	1.25	2650° F.
Test No. 2 (3 Tons)						
0	4.31	1.29	0.130	0.039	0.75	Not observed
10.1	4.09	0.37	0.125	0.036	0.15	
27.0	3.82	0.42	0.123	0.034	0.14	
Typical Oxygen Blow (40 Tons)						
0	4.33	1.42	0.128	0.029	1.20	2500° F.
6.0	4.31	1.29	0.130	0.034	0.75	
9.0	4.09	0.37	0.125	0.036	0.015	
13.0	3.82	0.42	0.123	0.034	0.014	2900° F.

Irregularities in the working of blast furnaces result in variations in metal analysis which cannot be evened out in passage through a large mixer, and cause fluctuations in the silicon content of the iron charged into the openhearths. The quantity of necessary limestone, the slag volume resulting, and the heat required to form the slag therefore vary considerably. In remarks before the 1937 meeting of the A.I.M.E.'s Openhearth Committee, L. H. Nelson has recommended the conditions of analysis and temperature of hot metal for optimum openhearth operations as follows:

Carbon	Over 4%
Silicon	0.90 to 1.10%
Sulphur	Under 0.035%
Manganese	1.60 to 1.90%
Phosphorus	Under 0.40%
Temperature	Above 2700° F.

As he pointed out, high-silicon hot metal, *per se*, had little effect on steel quality. However, low-silicon iron generally means high-sulphur iron and prolonged refining periods. A. J. Boynton said, in that same meeting, that the production of low-silicon, low-sulphur, high-temperature hot metal requires a "metallurgical miracle". This miracle can actually be performed by conditioning the hot metal, prior to pouring it into the openhearth furnace, with oxygen.

When relatively pure oxygen is blown into molten iron, the well-known bessemer reactions take place under conditions that are relatively easy to control and without the pyrotechnics common to the normal converter blow. The principal reactions, together with their heat effects per formula weight of O_2, are as follows (heat evolutions "from and at 70° F."; thermochemical data from the A.I.M.E.'s book "Basic Openhearth Steelmaking"):

$$Si + O_2 = SiO_2 + 370{,}800 \text{ B.t.u.}$$
$$2Mn + O_2 = 2MnO + 334{,}800 \text{ B.t.u.}$$
$$2C + O_2 = 2CO + 94{,}900 \text{ B.t.u.}$$

Silicon starts to oxidize first, followed by manganese. When these reactions are about half completed, carbon begins to oxidize to form carbon monoxide, which escapes as a gas through the slag. Since the reactions of silicon, manganese and carbon with oxygen are strongly exothermal, only moderate reductions in the silicon or manganese contents should provide substantial temperature increases in the hot metal.

Preliminary work was done in a 3-ton ladle, using 1-in. steel pipes heavily coated with KN refractory, through which oxygen was injected at a flowing pressure of 15 psi. The results obtained are shown in Table I. Large-scale tests were then made in a 40-ton ladle. A typical oxygen blow is also shown in Table I.

These tests on 40-ton ladles were carried to very low silicon to determine the effect of prolonged blowing on the manganese and carbon contents. Since manganese is important for controlling sulphur, it is obviously undesirable to push the silicon oxidation to a point where substantial quantities of manganese are lost. The reaction of oxygen with these elements proceeds stoichiometrically, and can be calculated on the basis of one point of silicon (0.01% or 0.2 lb. per ton of iron) requiring 2.76 cu.ft. of 99.5% oxygen at 60° F. and 30 in. Hg, one point of manganese 0.705 cu.ft., and one of carbon 3.20 cu.ft. The approximate theoretical heat effect from the oxidation of a point of silicon is 8° F., manganese 2° F., and carbon 3° F. It is not proposed that substantial quantities

of silicon be removed, as in the experiments, but that the oxygen reaction be used to control the silicon analyses and hot metal temperature to predetermined limits.

Certain precautions must be observed when injecting oxygen into the ladle of hot metal. The slag present on the iron is heavy, viscous and, generally, crusted over. While practically all of the oxygen is absorbed to form silicon and manganese oxides, some carbon monoxide is evolved, which (combined with the 0.5% of argon and nitrogen impurity in the oxygen) causes a gas accumulation under the crusted slag and considerable bumping in the ladle. As the metal and slag temperature increases, this initial difficulty disappears. Good practice appears to be the use of a cluster of refractory coated 1-in. pipes, with an oxygen pressure of not more than 30 psi.

The slag formed during the oxygen blow is quite voluminous and the escaping gases froth it still further. To take full advantage of the silicon reduction, this slag must be separated either by drawing off the metal through a teapot spout or by suitably arranged skimmers. Some consideration is being given to the plan of reducing the silicon on the blast furnace casting floor, where the usual slag skimmer can also remove the siliceous slag. The advantages of a lower slag volume in openhearth practice, coupled with hotter metal, are obvious.

Use of Oxygen During Meltdown

The openhearth bath, immediately following the hot metal addition, contains large quantities of unmelted scrap covering the limestone and often projecting as islands above the bath surface. Since the bath is essentially flat before the lime boil, great difficulty is often experienced in melting this scrap, delaying the inception of the lime boil. Such heats are said to be "slow to come off the bottom". They can usually be activated with very small additions of oxygen.

As an example, a 150-ton heat was slow in coming to a boil. The bath was flat and inactive, and while no islands of scrap projected above the bath, rodding indicated that large amounts of unmelted scrap were lying on the hearth. Oxygen was injected by steel pipes thrust through the center door and ending below the surface of the bath, at the rate of 600 cu.ft. per min. for 2 min. This proved sufficient to start the lime boil, thereby accelerating the rate of heat transfer from the gases to the bath, transforming a completely dead heat to one of normal activity.

Some caution must be used to avoid too violent an action, particularly in heats above 0.50% carbon. The carbon dioxide evolving from the limestone, the reaction of charge ore with the carbon, combined with the carbon monoxide from the carbon-oxygen reaction, may cause excessive foaming of the slag, some of which may flow out the doors onto the charging floor, but — more serious — furnace damage through scour of the refractories. While some experiments have used oxygen throughout the heat, starting at high-carbon levels in high hot metal practice, there are severe fume and refractory problems to be considered, and it is highly probable that the pig iron for such heats should be preconditioned with oxygen, or duplexed, before charging into the openhearth. The use of oxygen in small doses to control the bath activity and temperature, however, appears to offer many advantages without causing a fume or refractory problem.

Oxygen in Working the Heat

In working the openhearth heat, carbon and manganese are reduced by the combined action of the oxidizing gas atmosphere and by iron ore additions to the oxidizing slag. The reaction of iron ore and carbon is strongly endothermal:

$C + FeO = CO + Fe - 69{,}000$ B.t.u. per formula weight

In addition the entire mass of the cold ore must be heated to the slag temperature, requiring an additional 39,200 B.t.u. per lb-mol of carbon removed or a total of 108,200 B.t.u. The rate of carbon reduction is therefore limited to the speed with which heat can be transferred to the bath to compensate for this heat absorbing reaction.

The reaction of carbon with oxygen:

$2C + O_2 = 2CO + 94{,}900$ B.t.u. per formula weight

is strongly exothermal. Allowing for the sensible heat required to raise the oxygen to reaction temperature, 35,250 B.t.u. per lb-mol of carbon is released, or a net gain compared with ore practice of $108{,}200 + 35{,}250 = 143{,}450$ B.t.u. per lb-mol of carbon removed. This is equivalent to 11,900 B.t.u. per lb. of carbon.

Many heats that melt-in fast are delayed because the metal temperature cannot be raised rapidly enough to permit of full ore additions. The question of when to add ore to a heat thus becomes a matter of operator's judgment; the penalty for too rapid additions is a cold and inactive heat. Fast melting frequently results in higher carbons at meltdown, requiring additional oreing down to reach the analysis required. The use of oxygen to increase the rate of ore solution in the slag and to compensate for the chilling effect of cold ore additions is being given much study.

Figure 1 indicates a typical 140-ton heat, melt-

ing in at 1.00% carbon, whereupon 4000 lb. of ore was added, and a carbon drop at the rate of 0.30% per hr. established. Oxygen was added 60 min. later, when the bath had reached 0.70% carbon, through a 1-in. steel pipe at the rate of 650 cu.ft. per min., and the rate of carbon drop immediately increased to 1.20% per hr. Additional ore was added at 0.50% carbon, and after a momentary decrease in reaction rate, an even more rapid

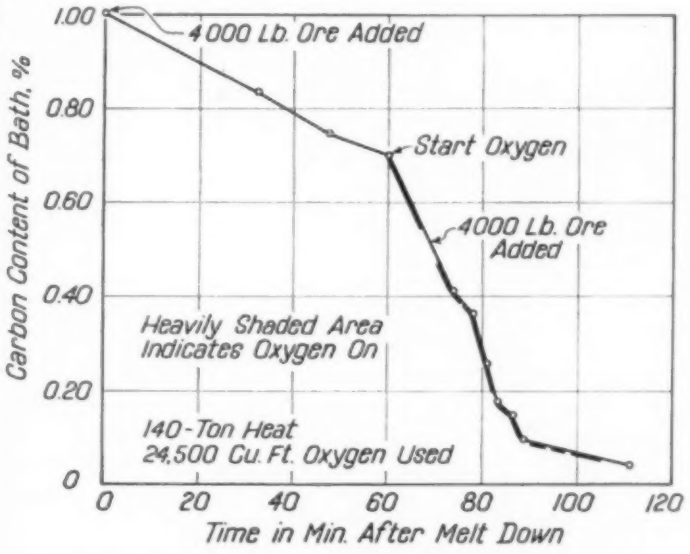


Fig. 1 — Progress of Carbon Elimination in a 140-Ton Openhearth Heat Under Combined Influence of Ore and Oxygen Gas

elimination (a rate of 2.40% per hr.) was established by the oxygen. As carbon fell below 0.15%, the rate decreased, reflecting the increased absorption of oxygen into the slag, and a lowering of the oxygen efficiency.

This combined ore-oxygen reaction offers many advantages over straight oxygen or ore practice including,

1. Moderate increases in the rate of carbon drop,
2. Recovery of some iron from the ore added — true only in carbon ranges above 0.15%,
3. Control of the bath temperature, and
4. Moderate rate of gas evolution, minimizing effects on the refractories.

Oxygen in Finishing the Heat

As the carbon content of a heat falls, it is more and more difficult to transfer heat to the bath because of the lowered bath activity and the higher melting point of the metal. This is particularly true in making low-carbon steels, where the melting point is high. Heats in the 0.02 to 0.05% carbon range commonly require 1 to 5 hr. longer finishing time than medium carbon steels. Frequently, when the bath temperature is not raised rapidly enough to compensate for the increased melting point, bath activity diminishes to the point where additional carbon must be added in the form of cold pig iron or hot metal, thus bringing the bath to a boil in order to secure adequate heat transfer.

The use of oxygen as a means of decarburizing low-carbon heats offers so many advantages over ore practice, that it has become a standard operation. It uses moderate quantities of high-purity oxygen. Since this operation has been described in detail by G. V. Slottman and F. B. Lounsberry in *The Iron Age* for Feb. 20, 1947, and in a paper before the 1947 spring meeting of the American Iron and Steel Institute, it will suffice to state that it has resulted in increases in production rates of 20 to 30%, reductions in fuel costs of 10 to 15%, increased metallic yields of 1 to 4%, and appreciable savings in refractory costs, coupled with the production of better quality steel.

Further applications of oxygen to the finishing period, now being actively investigated, involve its use with such compounds as ferrosilicon, for rapidly raising the bath temperature. Openhearth furnaces, toward the end of a campaign, rapidly lose their heating ability because of fouling of the regenerative system. Much time is therefore lost in bringing the bath to the desired tapping temperature. Small additions of ferrosilicon combined with a controlled oxygen blow can be used to adjust the bath temperature rapidly without materially changing the carbon content. In view of the large amount of practical work now being done with oxygen, it is certain that such uses will soon become standard openhearth practices.

Conclusion

While this paper has dealt largely with the developments of the past year in the application of oxygen as a chemical reagent in steelmaking, resulting from the first large-scale use in the openhearth in the United States in August 1946 at the Brackenridge plant of Allegheny Ludlum Steel Co., it is intended as a guide to metallurgical thinking in other fields. Many processes must exist in which oxygen would be entirely too expensive to be used as the sole oxidizing agent, but where medicinal dosages of oxygen, either alone or combined with metallic oxides, can produce significant results in increasing production rates and in lowering costs. The experience of the steel industry during the past year makes such a conclusion more certain.

The New President of the Society

Francis Benedict Foley

IN THE MINDS of his multitude of metallurgical friends, the two names "Foley" and "Midvale" are practically synonymous. Indeed, the association of these two well-known names in steel became established before the young men now entering the profession were born. 1947 will be FRANCIS BENEDICT FOLEY's 32nd year with Midvale, and his 20th as its director of research. He was born only a rifle shot away from his present laboratory, and his father before him once worked in Midvale's forge department. Except for a relatively brief absence of 10 years he has worked with Midvale, at its plant in the Philadelphia suburb called Nicetown, since 1905. So, in addition to being a metallurgist, he is also a deep-dyed Philadelphian, complete with scrapple (a native dish) and brotherly love (a local tradition).

Foley, who has turned 60 this summer, has the energy and outlook more commonly found in men some 10 or 15 years younger. He is suave, alert, and almost devoid of mannerisms; he talks easily and well about his chosen field and has a refreshing open-mindedness on any subject that comes to his attention. The influence of Benjamin Franklin is still strong in Philadelphia even after all these years, and Francis shares Ben's penchant for scientific investigation and his abiding interest in new things.

His type of mind and his professional attributes may well have been influenced as he matured by his association with Midvale, a firm which has much to do with the development of present-day metallurgical science. This plant, which dates back almost 100 years, produced about 75 years ago the first alloy steel used anywhere in bridges (chromium steel for the Eads Bridge across the Mississippi at St. Louis). Likewise, at the close of the 19th century the correct heat treatment of high speed toolsteel was developed by Taylor and White from toolsteels made at Midvale, and long used in Midvale's machine shops before being publicly exhibited and described. Midvale has always been a producer of high-quality material, some of it of so high a quality and so expensive that it was used chiefly for weapons and armament. The firm is today the leading proponent of the acid openhearth process of steelmaking. Foley has fitted in quite naturally with this Midvale tradition and has carried it on successfully.

When Foley first came in contact with metallurgy it was in a state of confusion, for the phenomena that the metals industries dealt with were either half-understood or, more often, not understood at all. Most of the knowledge of the time was empirical; beyond that there was only hypothesis and conjecture. Research, as we know it today, was only just beginning to be thought necessary by industrial firms; the steel industry, as a whole, awoke to the situation much later. Foley, then, has had the unusual privilege for a scientist of having witnessed almost the entire growth and development of his chosen science, and of having himself taken a prominent part in that development.

The Foley family emigrated from Ireland in the early 1850's. His father, Dennis J., was born in Norristown, and as noted before, worked at Midvale during the 1880's, but in 1888, the year after his son Francis was born, he left Philadelphia and went out to Dakota to join his brother in working a gold mine. His wife and four small children followed him, which turned out to be a sad thing, for he died the day of their arrival at Lead City. Mrs. Foley, who had no desire to stay in the solitude of South Dakota for gold, and who missed Philadelphia, thereupon brought her four small chicks all the way back home and finally arrived with them all intact — a feat more considerable than it may sound. When Foley was seven he was sent to Girard College, a secondary school in Philadelphia, and stayed until graduation in 1904.

Everyone has had a desire in their youth to follow some romantic calling. This writer, for example, always wanted to be a streetcar motorman and still does. Foley wanted to be an artist and still does. To this end, he went to work at the age of 16 (for $5.00 a week) in the art department of the Philadelphia *North-American*, a now-defunct newspaper, attended art school nights and Saturdays, and presumably got some sleep on Sundays. Apparently, the futility of trying to make an art career from scratch on a Philadelphia paper got to him, for in 1905, after a hard year of it, he quit and got a job as a clerk in the melting department at Midvale. This step has since worked out to the satisfaction of everyone involved.

In 1907, during a depression, now forgotten by all except those who lived through it, he was shifted out of the office and put to work on the floor where he did a man's work at the furnaces. The customary stint was 11 or 13 hr. a day — 91 hr. a week on the long turn — and "labor's gains", as we know them today, had not been thought of. After two years of this apprenticeship, he was rewarded by being transferred to the staff of Midvale's research department, which was started in 1902 (under Radclyffe Furness).

Recalling those early days, Foley is amazed at how little was actually known about what was going on inside a heat of steel. In an effort to find out as much as he could, he got hold of the writings of the few men who *did* know something — such men as Henry Marion Howe — and studied

them both on and off the job. At first everything was confusing, for there were all sorts of theories and schools of thought about steelmaking chemistry and steel treating physics, but in the end Foley became a disciple of Howe and his ilk and tried to follow their logical conclusions. It was all quite difficult, for he recalls sadly that there was no accurate measurement and control of high temperatures, no rapid methods of chemical analysis, not even an accurate hardness test. Things picked up fast, however, with the advent of the First World War, and improved instruments and techniques were developed rapidly.

It was in 1917 that Francis Foley committed the great heresy of leaving the precincts of Midvale. It was 10 years before he came back, but in that period he found experiences and associations which rounded off his rough edges and ultimately thrust him into the top bracket of his profession. His work at Midvale had attracted the attention of Samuel L. Hoyt who persuaded him to join the faculty of the University of Minnesota as his assistant in the Department of Metallography, but the Government shortly "requisitioned" him for war work with the Bureau of Mines. So (this gets complicated) Minnesota gave him a leave of absence and he investigated the production of ferromanganese throughout the country for the Council of National Defense.

In 1918 (still on leave of absence from Minnesota) he was put in charge of the iron and steel division of the Bureau of Mines and remained in that capacity until 1924. During this six-year tour of duty he became well acquainted with steels for ordnance, mining, and oil-field drilling — all stuff of high quality. As a member of National Research Council's committee on carbon steel he came to work with Henry Marion Howe, and when Howe was on his deathbed Foley did most of the preparation of the report of this final work of the master.

Foley's close-range association with the great Howe has left him with some interesting memories. Howe was over 70 at the time and not always the easiest person to work with. But Howe's crotchets and eccentricities were as nothing, Foley says, compared to the flashes of insight and intellect that he gave off, and Foley thinks that the year he spent working with him was one of the most priceless experiences any metallurgist could have. Howe's self-appointed role, late in life, was to collect the findings of other investigators and discover the pattern they made. He was, as he expressed it to Foley, "not a maker of bricks but a builder of cathedrals". A whole year of this must have been heady stuff for the former furnace-tender who had studied Howe's books between heats.

It is typical of the Philadelphian in Foley that when, about this time, he was offered twice his salary to work for a steel company in Pittsburgh, he declined because he doubted that living in the smoke and dirt of the steel capital could be justified by any amount of money when an opportunity to collaborate with Howe was the alternative and added incentive. There have doubtless been Pittsburghers who felt the same way about living too close to the odorous Schuylkill River. In any event, in 1926 Foley returned to Philadelphia, to scrapple, and all the other worthwhile things, as director of research for The Midvale Co. Thus his career had completed a 360° spiral, for he was back where he had started, only much higher up.

Today, after rounding out more than 40 years as a metallurgist, Foley is as heavy with honors as an ambassador. The list of his societies and of his many technical papers would take up about 200 lines here, far too many for the space allowed. He was chairman of the Philadelphia Chapter of the American Society for Metals in 1934-35; a trustee of the national society from 1938 to 1940; national treasurer from 1941 to 1943, vice-president in 1946 and president in 1947.

Foley's first wife was the former Anne Flaherty, whom he married in 1915, and who died in 1936. When their son Gerard grew up, his father — strongly influenced by his admiration for Sir James Irvine — sent him to the University of St. Andrews in Scotland, of which Sir James is the vice-chancellor. It is Foley's belief, and the belief of many others, that American colleges in general offer too narrow and specialized a training, and he is particularly in favor of the broader and more classical offerings for undergraduate study in the older British schools. Mutual friends will watch Gerard's progress in the research department of Leeds & Northrup to check the soundness of his father's beliefs.

Francis Foley's second wife, whom he married in 1938, was the former Katherine Campbell. They have an eight-year-old daughter, Frances, who with Mrs. Foley's 16-year-old son, John, completes the family circle. When the president of the S is not engaged in homework for his professional societies, or is not making talks to chapters or to college undergraduates, he puts in his evenings at such things as building a doll's house for daughter (a replica of their home, one inch to the foot) or painting a portrait of some neighbor or friend, which sometimes he can be persuaded to do.

For all anybody knows, FRANCIS BENEDICT FOLEY is still on leave of absence from the faculty of the University of Minnesota. He probably spends some time worrying about that, too.

EDWARD C. MCDOWELL, JR.

Resistance of Sensitized Stainless Steels to Boiling Nitric Acid

By **Raymond S. Stewart**
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The Huey test — boiling stainless steel samples in 65% HNO_3 for five 48-hr. periods and weighing the corrosion loss — was originally proposed as a means of evaluating the highly resistant alloys in respect to their general corrosion resistance. In some quarters, however, its use has been extended to appraise the effect of "sensitizing" heat treatments, which induce accelerated intergranular (not general) attack. Mr. Stewart presents data that show such an extension of its utility is unwarranted and should be discouraged.

SHORT-TIME, accelerated corrosion tests are used quite extensively to predict the suitability of stainless steels for service applications, particularly those present-day commercial modifications of the austenitic chromium-nickel steels popularly referred to as 18-8. Of these tests, the boiling 65% nitric acid test has become increasingly popular since 1930 when it was proposed by W. R. Huey as a corrosion test for research and inspection of alloys. This popularity resides in its simplicity and reproducibility of results, and as a laboratory test capable of giving quantitative data. Although it was stated emphatically by Huey in his paper (*Transactions* A.S.S.T., Vol. 18, 1930, p. 1126) that "the corrosion rate obtained shows the resistance of the sample tested to the corroding solution used under the conditions of the test made", many laboratories use the data as a basis for acceptance of stainless steels for service in other media than boiling 65% HNO_3 and under entirely different conditions.

From the voluminous data in the literature it is evident that the resistance of almost all the austenitic stainless steels, when in the annealed state, to 65% nitric acid is high, and little difference exists between the corrosion rates of the various steels. So-called sensitizing heat treatments, that produce a metallurgical condition susceptible to intergranular attack,* result in high losses when the metal is tested in boiling 65% nitric acid. This, however, does not permit one to assume that immunity to intergranular attack after so-called sensitizing treatments is an indication of high resistance to general attack by boiling 65% nitric acid. For example, the titanium-stabilized Type 321 steel (low-carbon, 18-10 Cr-Ni) is inferior in resistance to 65% nitric acid as compared to the columbium-stabilized Type 347 steel (low-carbon, 18-11 Cr-Ni), both subjected to a sensitizing heat treatment and immune to intergranular attack.

In spite of this knowledge the nitric acid test has been used too frequently as a measure of the susceptibility of stabilized austenitic stainless steels to intergranular attack. Conversely, there has been a marked tendency to assume that low resistance to 65% nitric acid is *a priori* an indication of low resistance to other media, in spite of the before-mentioned words of caution by the originator of the test at the time he proposed it.

In view of these circumstances a study was made of the behavior of plain 18-8 (Type 304) as well as 18-10 Ti and 18-11 Cb, with respect to variable concentrations of nitric acid and prior heat treatments of the steel. This present article sets forth the differences found, and at a later date the author will present the results of other work

*The laboratory test is usually boiling in a so-called Strauss solution (47 cc. H_2SO_4 of 1.84 sp. gr. plus 13 g. $CuSO_4 \cdot 5H_2O$).

Table I — Chemical Analyses of the Stainless Steels Tested

Type	C	Mn	P	S	Si	Cr	Ni	Ti	Cb	Ratio*
304	0.07	0.45	0.018	0.007	0.59	18.22	8.68			
321	0.05	1.10	0.027	0.015	0.37	17.65	10.20	0.28		5.6
321	0.05	1.32	0.028	0.011	0.46	18.48	10.16	0.59		11.8
347	0.08	1.37	0.023	0.007	0.39	18.48	11.23		1.02	12.7
304-C†										
Ingot 1	0.050	0.44			0.33	19.06	8.83			
Ingot 2	0.076									
Ingot 3	0.098									
Ingot 4	0.13									

*Ratio of titanium to carbon or columbium to carbon.
†Laboratory induction heat; all others commercial heats.

now in progress that will attempt to throw some light on the differences observed in the test data now presented.

Eight specimens of each of the stainless steel Types 304, 321, and 347, approximately ½ x 1 in., were cut from commercial steel plates which were ⅛ to ¼ in. thick. Their chemical analyses are given in Table I. These sections were annealed at 1950° F. for 20 min. and water quenched, and then sensitized by being heated at 1250° F. for 2 hr. and then air cooled. Since it was not the purpose of this investigation to evaluate the effect of any number of the possible sensitizing treatments that could be used, the work was restricted to this one condition, as it is commonly used by many laboratories. After heat treatment, the specimens were machined and ground all over to a 120-grit finish, and accurately measured and weighed.

Duplicate specimens of each grade were subjected to three 48-hr. periods in boiling nitric acid solutions containing 35, 45, 55, and 65% acid by weight. Each specimen was tested in a separate flask with a minimum of 150 cc. of solution per sq.in. of surface area. Each specimen was suspended by a loop of glass rod passing through a drilled hole so the metal hung freely in the solution. The acid was mixed in a large carboy in sufficient quantity for the number of tests made in each concentration; this increased the accuracy in measurement and gave assurance that the acid strength of solution in each flask was identical. The acid used was the duPont-Grasselli c.p. reagent, which conforms to the American Chemical Society specification for analytical reagent chemicals, and, in addition, has a maximum fluorine content of 0.0001% and a maximum PO_4 content of 0.00002%, as recommended by the A.S.T.M. for this test. The corrosion rates, expressed as inches penetration per month, were calculated for each period and averaged for the three periods. These data are shown in Fig. 1.

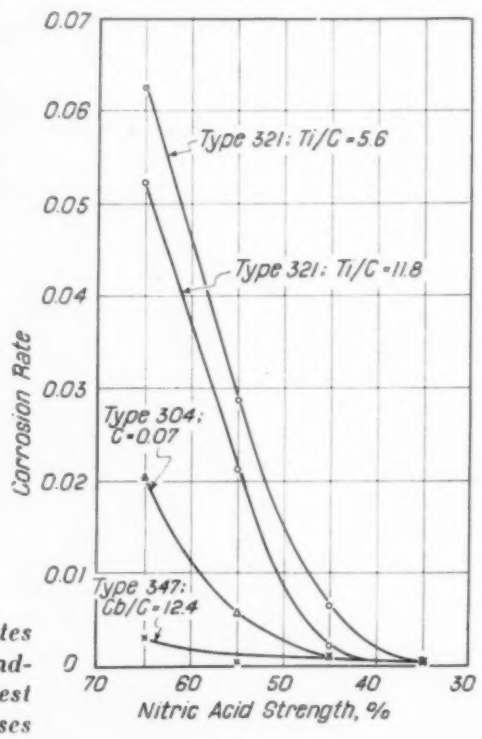

Fig. 1 — Decrease in Corrosion Rates (In. per Month) of Three Standard 18-8 Steel Types in Huey Test as the Acid Concentration Decreases

The rate of corrosion of sensitized Type 321 (18-10 Ti) steel was found to decrease to a considerable extent as the concentration of the acid medium was reduced from 65 to 35%. This effect of acid strength was found to be similar also for the plain 18-8 steel, but to only a moderate degree. The test results on the columbium grade were affected only slightly by acid concentration. From Fig. 1 it can be seen that the corrosion rates of the three types of stainless steel tested are within a rather close range for 45% acid and are practically identical for 35% acid.

A comparison of the corrosion rate curves of the two titanium steels, Fig. 1, shows that the Ti/C ratio has very little effect. The general characteristics of the curve are the same for the two alloys tested. For the four nitric acid solutions used, the steel with the Ti/C ratio of 11.8 has somewhat better corrosion resistance than the one with the ratio of 5.6. Since these are two commercial heats with some differences in chemical composition other than titanium content (as may be seen in Table I) it is difficult to surmise whether it is the Ti/C ratio *per se* or the higher chromium or silicon content that influences the corrosion resistance in nitric acid.

In order to show that the corrosion rates of sensitized Type 304 steels are dependent on the carbon content (a point that

seemed probable from a study of miscellaneous scattered data, both published and unpublished) a 30-lb. heat was made in our laboratory induction furnace and poured into four ingots, with progressive additions of wash metal before each tap, to provide a range of carbon contents between 0.05 and 0.13%. These ingots, the analyses of which are given in Table I, were forged to ½ x 1-in. bars in the temperature range of 2250 to 1850° F. Sections of each bar were heat treated, machined, and ground in the same manner as the commercial steels described above, and duplicate specimens were subjected to three 48-hr. periods in boiling 65% nitric acid.

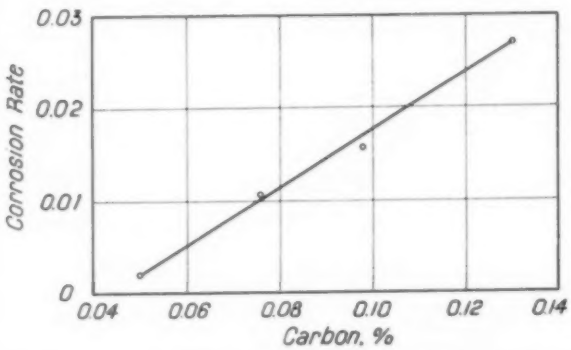

Fig. 2 — Corrosion Rate (In. per Month) of Sensitized Type 304 (Plain 18-8) Decreases to Vanishing Amounts as the Carbon Is Lowered

The results obtained from testing these 18-8 laboratory steels, with carbon as the only variable, clearly show that the resistance of this grade (in the sensitized condition) to boiling 65% nitric acid decreases as the carbon content increases. This is shown in Fig. 2. This indicates that the sensitized plain 18-8, with 0.05% carbon, yields a corrosion rate *in the nitric acid test* even lower than that of sensitized Type 347 steel, the best of those shown in Fig. 1.

Since carbon content is a factor that influences the corrosion rate of sensitized 18-8 steel, the differences in corrosion rates of Types 304, 321, and 347 tested might be ascribed to the occurrence of carbides of different composition in the three grades. When it is noted, however, that the 0.13% carbon laboratory heat corroded at approximately half the rate of either of the titanium-bearing steels in boiling 65% nitric acid, it becomes evident that the high losses observed in the latter could not be due entirely to precipitated carbides. A titanium steel with only 0.05% carbon would have 0.20% titanium combined as carbide (assuming only TiC present) to give a total weight of 0.25% in the carbide phase. The 0.13% carbon 18-8 laboratory heat, on the other hand, would have approximately 3.12% chromium combined as Cr_4C to give 3.25% of the entire weight as the carbide phase. The formation of this chromium carbide phase would cause considerable impoverishment of chromium at the grain boundaries and supposedly render that portion somewhat vulnerable to corrosive attack in the nitric acid. In the titanium steels, however, there can be no impoverishment of chromium at the grain boundaries produced by carbide formation, and the complete dissolution of *all* the TiC phase in the acid, if that were possible, could account for only 0.25% weight loss instead of the 25% weight loss which actually occurred in these small specimens in the boiling 65% nitric acid solution.

Thus, there is obviously some peculiar effect of the boiling 65% nitric acid on the matrix in the Type 321 titanium-bearing steel, which is of a general corrosive nature and has no relation to carbide precipitation. This effect is not obtained with 45% or weaker nitric acid, and there is no reason to assume that other types of solutions and of different concentrations would or would not yield similar trends.

Conclusions — 1. The corrosion rate of Type 321 steel (titanium bearing), sensitized at 1250° F. for 2 hr. and air cooled, decreases markedly as the concentration of test medium is lowered from 65 to 35% boiling nitric acid. That of Type 304 (plain 18-8) decreases to a moderate extent, while that of Type 347 (columbium bearing) decreases only slightly.

2. In solutions of 45% boiling nitric acid and less, there is no appreciable difference in the corrosion resistance of the three grades that were tested.

3. The Ti/C ratio has only a minor effect on the corrosion rate in nitric acid. The steel with 5.6 times as much titanium as carbon had a slightly higher rate than the one with the 11.8 ratio in all the concentrations of nitric acid used, when tested in the sensitized condition.

4. The corrosion rate of sensitized plain 18-8 steel in boiling 65% nitric acid increases with an increase in carbon in the range of 0.05 to 0.13%.

5. The corrosion resistance of all sensitized plain 18-8 steels, even that with 0.13% carbon, is considerably better in boiling 65% nitric acid than either of the two Type 321 (titanium bearing) steels tested.

6. The low resistance of sensitized Type 321 (titanium bearing) steel to boiling 65% nitric acid is not due to carbide precipitation. Thus, the Huey test is definitely unsuitable for evaluating the tendency toward intergranular corrosion of Type 321 steel.

Where Do We Go From Here?

Molotov

Extracts from a speech in Moscow on Nov. 6, 1947, by Soviet Foreign Minister, as translated by Soviet radio monitor.

THE SOVIET Union has invariably carried out, and is carrying out, the policy of peace and international collaboration with all the countries which evince a desire to collaborate.

This policy is opposed at present by another policy, based on quite different principles. Here we can talk first and foremost of the foreign policy of the United States as well as that of Great Britain. They are acquiring ever new naval and air bases in all parts of the globe, and even adapt whole states for such like aims, especially if closely situated to the Soviet Union. It is clear that the creation of such military bases is not designed for defense purposes, but as a preparation for aggression.

It would be a good thing for all this to be known to the American people, for under the so-called Western "freedom of the press", when almost all newspapers and radio stations are in the hands of small aggressive cliques of the capitalists and their servitors, it is difficult for the people to know the real truth.

It is interesting that in expansionist circles of the U.S.A. a new, peculiar sort of illusion is widespread. While having no faith in their internal strength, faith is placed in the secret of the atom bomb, although this secret has long ceased to exist. The atom bomb, as is known, is not a means of defense but a weapon of offense. Many are indignant that the U.S.A. and Great Britain hamper the United Nations from adopting a final decision in the prohibition of atomic weapons.

During the second World War, American industry grew rapidly and began to yield enormous profits to the capitalists and state revenues, which American state monopoly capitalism is putting into circulation and applying to exert pressure everywhere in Europe and China, in Greece and Turkey, in South America and the Middle East, to impose its will on them under the banner of unsolicited American guidance and to pave the way for the world domination of the United States of America.

Today the ruling circles of the U.S.A. and Great Britain head one international grouping, which has as its aim the consolidation of capitalism and the achievement of the dominations of these countries over other peoples. The policy of the Soviet Union is based on opposite principles, on the principle of respect for the sovereignty of all states, big and small, on the principle of non-intervention in the internal affairs of other states.

Under the present conditions, this demands the uniting of all forces of the anti-imperialist and democratic camp in Europe and beyond the boundaries of Europe so that an insurmountable barrier shall be created against imperialism, which is becoming more active, and against its new policy of aggression.

What can the policy of imperialism offer people? Nothing but strengthening of oppression, the rebirth of the vestiges of hated fascism and imperialistic adventures.

Forrestal

Extracts from a speech in New York City on Oct. 1, 1947, by Secretary of Defense, U.S.A., before Army Ordnance Assoc.

I SPEAK tonight as the head of the country's military establishment to a group of business leaders who have manifested in tangible fashion their interest in national security. No group in any country is more desirous of maintaining peace than the people engaged in business. One of the many fallacies generated by Marx and Engels is the thesis that the form of private ownership we know as business capitalism is provocative of war.

This theory as an interpretation of history, which it pretends to be, has no validity. Careful research discloses not the slightest degree of historical support for the idea that the businessmen have precipitated wars between great nations.

American business does not want war and neither does American labor. American businessmen base their actions on the assumption that increasing markets for goods will come from the maintenance and extension of high standards of life in our own country and ultimately throughout the world. Decent standards of living shrink and diminish in wartime. The final and overriding reason that businessmen do not want war is because they are men of intelligence and therefore know the terrible waste of human life that war involves.

War does not provide permanent solutions to international political problems, however much misguided leaders of states sometimes think it does. Rather it is the confession of the failure of men to deal successfully with each other by reason and negotiation instead of through violence. War substitutes the law of force for the force of law.

There is not a man in this audience who is not desperately anxious to see the world embark upon a century of peace and of reconstruction and repair. But I also believe that no one in this audience will differ with this statement: Until all nations are willing to accept the principle of the rule of law rather than the rule of force it would be as foolish to risk unilateral disarmament as it would be to abolish fire departments in the hope of ending all fires.

During the war, American capital and labor produced and transported to our allies enough equipment to outfit 2000 infantry divisions, 588 armored divisions, and six air forces as large as

The Quantometer—

a Tool for the Metallurgist

By Walter Bonsack
Director of Laboratories
The National Smelting Co.*
Cleveland

A direct reading spectrometer speeds the quantitative analysis of light metal alloys for 20 individual elements. Light from a single selected spectral line cast by each element is absorbed by an individual photo-electric cell, and the current so generated is multiplied by electron tubes to where it drives a counter and indicates the result on a printed tape. Close track can be kept of refining operations without long waits for analytical results; uniformity and quality of ingots can thus be improved. Many research problems requiring accurate determinations in numbers sufficient for statistical analysis will be expedited.

ADDITION this year of a 20-station "Quantometer" to our laboratory equipment was a further and concrete recognition of the tremendous developments in the technology of aluminum casting alloys during the past decade. Permitting more rigid control of metal in all stages of manufacture than hitherto economically possible, this is believed to be the first such instrument to be installed for quality control in the manufacture of aluminum casting alloys for use by foundrymen and die casters.

Aluminum casting alloys, like many others, are becoming more and more complex in their compositions. Whereas about 10 years ago, alloys with one, two, or three alloying elements mainly were used, today alloys with more than ten such elements are very common. This numerical increase is found mainly in the minor alloying elements, either added to alloys intentionally or which have crept in as impurities. Whatever their origin, they must be carefully controlled so as to produce alloys with consistent properties.

The smaller the amount of an element present, the greater are the difficulties of chemical analysis. Analyzing elements above one or two per cent is one matter, but determining elements in the ranges below 0.5% down to a few thousandths is another. Generally speaking, the smaller the amount present, the longer is the time required and the greater are the difficulties in accurate quantitative chemical analysis.

*National Smelting Co. will be known after Jan. 1, 1948, as the Apex Smelting Co., Cleveland Plant.

our own largest air force — the Ninth. Since the war, American capital, labor, and business have exported $3,400,000,000 of food, $4,500,000,000 of machinery, and $2,300,000,000 of textiles in addition to billions of dollars' worth of other goods. All of this was done by a nation functioning under that supposedly weak form of government — democracy — and under that supposedly inefficient economic system — capitalism.

We have no desire to conquer the persons or the property of other people, nor any desire to control their ideas and their thoughts. We think of human beings all over the world, toiling upward painfully and slowly toward the light of greater freedom and greater well-being, not as a vast amorphous mass of faceless men but as a collection of individuals each carrying in his soul and in his heart the light of God's grace, entitled to be considered as a human entity and not as a mobile item on an ant hill.

The only "cold war" that we are waging is against hunger and desolation, against oppression and tyranny, against disease and despair wherever they exist. That has been our philosophy and faith since the founding of the Republic.

And it still is.

The need for speedier and more accurate methods was early recognized. This was met by the spectroscope and spectrograph. Nevertheless, spectrographic methods still are comparatively slow, inasmuch as they require photographing of the respective spectra, processing the film or plate, then measuring the density of the spectrum lines and calculating the amount of each element that produced the observed line.

During this analytic time, which is of considerable duration, the production furnace must "swing" — or wait. Not only is productive time thus lost, but changes in composition may occur during this period which will throw the alloy off specification or may spoil the metal in other ways — as by gas absorption, segregation of heavy elements, or other changes. It often happens that after such a waiting period, further adjustments have to be made and new samples must be analyzed, resulting in yet longer time and possible material losses.

From these few considerations alone, it is apparent that a method of procuring an immediate analysis is very desirable. Applied Research Laboratories of Glendale, Calif., succeeded in producing such an instrument in the Quantometer — a direct reading spectrometer, which gives simultaneous analyses of as many as 16 elements in one sample.

Since the actual time required by the machine is a matter of seconds, samples can be run in duplicate or triplicate with very little extra expense. By surveying two or three analytic results rather than one, the metallurgist can obtain a more certain result through "evening out" possibilities of slight segregation in the samples.

Description of Equipment

What is the Quantometer? Generally stated, it is a machine which applies electronics to the problem of quantitative analysis of solids — a direct reading spectrometer. It avoids the time-consuming processes of developing, fixing, and washing photographic plates or film, and the subsequent measurement of individual lines on these plates or film. The instrument consists of a grating spectrograph; in place of a plate holder, a series of photo-electric receivers is placed in the focal surface. These can be moved and adjusted so that each receiver picks up but one spectral line; that one is the preferred line for the element for which an estimate is desired. The amount of light in one spectral line is very small, but the use of the very sensitive photomultiplier-type tubes in the receiver amplifies the tiny currents generated to the point where counters can be driven, which in turn drive tapes on which concentrations can be typed and read off directly.

The length of time over which the measurement is made is governed by one counter, which measures the energy from an internal standard. (For measurements on aluminum alloys this is an aluminum line.) A stop is placed on the tape for this counter, which automatically shuts off the whole machine when the total energy received from the aluminum line has reached a desired value. Thus the readings on any other line can always be taken as a certain fraction of the intensity of the aluminum line. For a given element, the amount of rotation of the tape can thus be translated directly into concentration, and the concentrations can thus be printed directly on the tape. The results may, however, vary from one standard alloy to another — so in order to avoid readjusting the machine each time the alloy is changed, a set of conversion tables is made up.

This new tool for the metallurgist opens up possibilities not only to correct the difficulties to which earlier reference has been made, but goes much further into precision control in preparing alloys on a production basis.

Much of the raw material used in the metal industry originates from secondary metal, popularly called "scrap". Although it is purchased by the smelters primarily as segregated material and in large lots, the possibility that one type of alloy scrap is contaminated with others is always present. Even careful sampling of a lot of raw material does not always give the complete story on the uniformity of the lot, and variations from uniform-type scrap usually only appear when the raw materials are melted.

For example, many individual types of castings or machine parts are made alternatively of aluminum alloys or of magnesium alloys. Many others are made of one of several different aluminum alloys, depending on preference of the designer. If, then, the surface finish is the same for both types, segregation by sorting is next to impossible since the shape is the same.

Consider some specific examples. Cylinder heads for air-cooled aircraft engines have been extensively made of an aluminum-base alloy containing 4% Cu, 2% Ni, and 1.5% Mg, and also of one with 10% Cu and 0.25% Mg. Therefore scrap actually containing both alloys — but which had been bought as one alloy and accidentally sampled as the first alloy — caused a great deal of trouble when the final analysis of a furnace bath of several tons appeared 7% Cu, 1% Ni and nearly 1% Mg. Critical sorting of the remainder of the shipment then established the fact that it was actually a mixture of the two alloys described above.

Many more specific examples could be cited. The point is, however, that in using scrap, one is never free of such contaminations or mixes. It is therefore necessary to control each step in alloying by analysis of the materials in the furnace. Chemical and spectrographic methods have been used in the past, but the time consumed is too great. Greater speed and accuracy today are essential.

With the aid of the Quantometer, we are now able analytically to control each step in alloying at National Smelting Co. Since the analysis as such takes only one minute at most, and the sampling and preparation of the samples can be accomplished in a very few minutes, a complete report on the composition of the alloy can be returned to the furnace control desk within 15 min. from the time the ladle of liquid metal is withdrawn from the bath.

This, then, affords a greater number of practically possible samplings. At each charge of raw materials going into the furnace a complete analysis can be made, and the progress of each heat toward its final composition can be watched and guided with greater certainty.

Many of the present-day raw materials contain large percentages of magnesium, too much for the casting alloys. Removal of magnesium is still expensive and unpleasant. During the removal period frequent analyses are necessary *(a)* to assure proper progress of elimination, *(b)* to avoid wasting fluxes, *(c)* to avoid wasting furnace time and manpower. Here again the Quantometer has been of great assistance due to its high speed and accuracy.

An example is an alloy which was required by specification to contain 0.3 to 0.5% magnesium. Due to the raw materials charged, the heat came up with 1.79% Mg. This surplus had to be worked down, and the table below shows the rate of elimination by Quantometer analysis, which was later followed by chemical analysis as a check.

Sample No.	Quantometer Result	Chemical Analysis Check
C-1	1.79	1.85
C-2	1.17	1.18
M-3	0.87	—
M-4	0.71	0.68
M-5	0.45	—
F-1	0.37	0.37
F-2	0.37	0.37
F-3	0.36	0.36

During all these magnesium determinations, the constancy of all other elements could easily be followed merely by recording the results shown on the various tapes. It would have been quite expensive to get all this information in the usual spectrographic analysis, and impossible by visual spectrometric and ordinary chemical analysis.

Magnesium and sodium are elements which occasionally show tendencies to be lost to slag or vapor during excessive waiting time, or even during pouring. It is therefore desirable to check the finished alloy for these elements constantly during the pouring period.

High melting alloying elements, such as nickel, manganese, titanium or copper, have a tendency to sink to the bottom of the furnace — or to float, as does silicon, for example. Solution of such elements in the bath is a matter of temperature, time, and agitation. To make certain that elements so added are completely dissolved and thoroughly disseminated, analysis is necessary. The Quantometer again excels

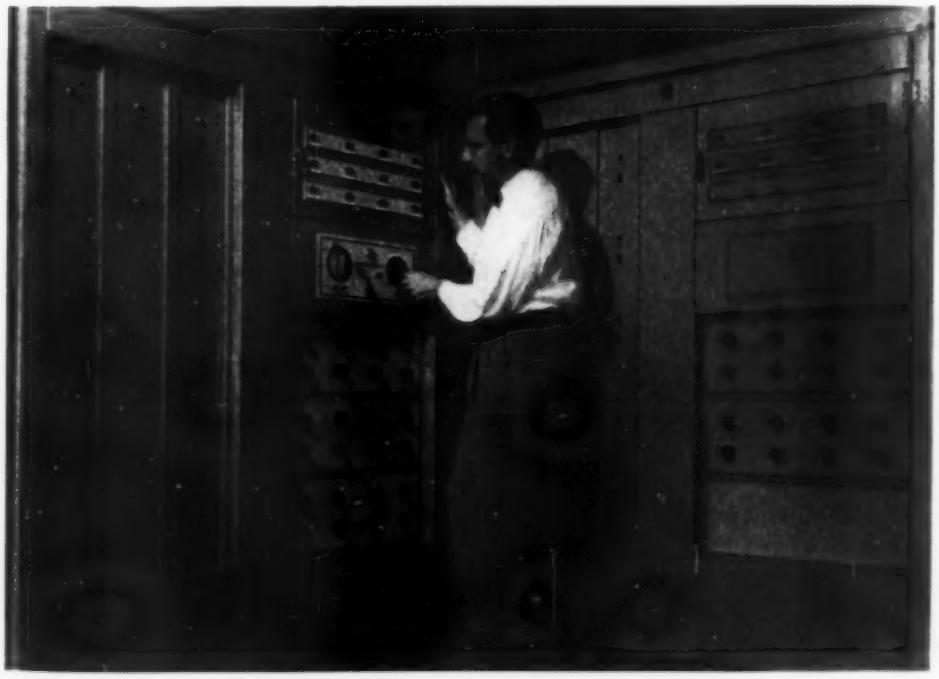

Fig. 1 — K. B. Thomson, Head of the Spectrographic Laboratories, at the 20-Station Recording Consoles Which Give Direct Readings of the Percentages of Alloying Elements

any other known method in accuracy and speed.

Many prewar specifications on aluminum alloys were either very narrow or very wide. The alloys with the narrow specifications correspondingly carried high physical property requirements, and those with wide specifications carried relatively low requirements. It was obvious that this division was made to distinguish between prime and remelt alloys.

During the last decade, however, it was pointed out by the author* that alloys recovered from secondary metals can possess superior physical properties if the influencing alloying elements are properly controlled and adjusted to each other in the proper ratio. For example, the ratio of iron and silicon is critical in pure aluminum which is to be used in die-cast electric motor rotors. Hot shortness and electrical conductivity are both dependent on the proper balancing of these two elements, as well as the strict control of trace elements like copper, nickel, manganese, titanium, chromium, tin and lead.

The manganese-iron ratio in aluminum-silicon alloys is another example utilized at present. A comparison of the A.S.T.M. specifications B-58, B-112 and B-125 of 1937 with today's A.S.T.M. specification B-179 will indicate the trend. The only footnote on minor elements found in the 1937 specifications is on the order of "Total of all elements other than aluminum not to exceed 14.5%". Today one finds: "If the copper and iron content exceeds 0.5%, a manganese content of at

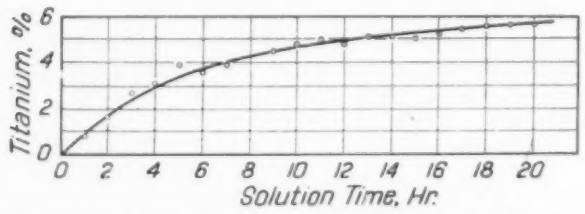

Fig. 2 — Results of Hourly Titanium Analyses of a Heat That Was Being Brought to 5.75% Ti

least 0.3% is desirable," or, "If the iron content exceeds 0.4%, it is desirable to have manganese present in amounts equal to one half of the iron."

From such considerations, new alloys have been developed from some of the old basic alloys made of secondary metal, and these new alloys have physical properties equal to some of the old "prime" alloys. Of course they demand accurate control of composition, which is hardly possible to do economically by chemical methods. Spectrographic analysis has been used up to now and is logical — but expensive. The Quantometer is the more economical and accurate approach for, as is obvious from the preceding discussion, to obtain the closely balanced compositions now necessary, constant analytical checks of the heat in the furnace are necessary.

Developmental Possibilities

The Quantometer is not only a production tool, however, but is also a very desirable instrument for the study of other problems in which the accurate determination of composition is of importance. Consider spectrographic standards, for example. These are made in the shape of cast pins or disks. These castings are sampled by sawing and drilling a number of them, and then chemically analyzing them very thoroughly. The result is the average analysis of a number of samples. No guarantee is given that each pin or disk casting falls very close to this average composition, and there are possibilities of relatively large variations from casting to casting. With the Quantometer, however, enough tests can be made on a sufficiently large number of pins or disks to determine statistically the uniformity of the "standards to be" before time and money are spent to determine by extremely accurate chemical methods what the analysis actually is.

Composition changes in castings due to solidification shrinkage can accurately be followed by Quantometer analysis. Segregation can be studied with such a number of analyses that the problem can now be attacked statistically.

Another example is given in the graph, Fig. 2. The speed of solution of a 50% titanium-aluminum alloy in aluminum at 2500° F. was studied by Quantometer analysis. The object was to obtain a melt containing 5.75% titanium. A sample was analyzed every hour, and the heat could be tapped at the correct time.

Information about hard spots in a casting, when they are metallic in nature, can easily be obtained by running a line of analyses across the hard spots and observing radical changes in one or more of the alloying elements.

As the experience with this instrument increases, many other problems will most likely be solved with the help of the Quantometer. The instrument is so new that all of its possibilities are not even known. We feel strongly that this new tool for metallurgists will help us tremendously in our studies of the influences of alloying elements on the properties of aluminum alloys and magnesium alloys.

*"Discussion of the Effect of Minor Alloying Elements on Aluminum Casting Alloys", by Walter Bonsack. American Society for Testing Materials *Bulletin*, Aug. 1942, p. 45, and Oct. 1943, p. 41.

Flame Hardening of Armor Plate*

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Flame hardening of the surface of low-alloy armor plate by successive passes of a torch 6 in. wide was found to produce a hardened case, uniformly 0.25 to 0.30 in. deep. Surface hardness on 0.24 to 0.31 carbon plates was 510 Vickers. However, there was always a tempered and soft line where successive passes of the heating torch overlapped. A further difficulty in thin plate was the excessive amount of warpage whereby the plate became dished with hardened surface concave. Subsequent straightening was likely to crack the plate.

A CONSIDERABLE amount of work has been published concerning the use of flame hardening on various machine parts. Often the geometry of the part has to a large measure influenced the results. The authors have had occasion to investigate some of the problems encountered in the flame hardening of flat plate in connection with research on armor and present the following information as a summary of this work.

Material — The steels used were of the weldable low-alloy type. Their composition varied over a considerable range, limits of analyses for the usual elements being as follows:

	Low	High
Carbon	0.24	0.31
Manganese	0.84	1.67
Phosphorus	0.013	0.023
Sulphur	0.013	0.025
Silicon	0.14	0.76
Nickel	—	1.29
Chromium	—	1.05
Molybdenum	0.19	1.55

Three thicknesses of plate, ½, 1, and 1½ in., were used. Most experimental work was on 12x18-in. surface areas of these thicknesses, with some hardening being done on 36x36-in. surface areas in the 1-in. thickness. All plates were originally water quenched and drawn to hardnesses as follows:

½ in.	Brinell 341 to 363
1 in.	321 to 341
1½ in.	262 to 302

Apparatus layout is schematically shown in Fig. 1. The flame hardening torch was designed to produce a hardened layer 6 in. wide. Flame orifices (82 in number, of No. 64 drill) were arranged in four rows, and supplied with oxygen and acetylene by two mixing blowpipes. Either two or four rows of flames could be used for hardening. The quenching head was attached to the hardening torch and the assembly guided along the plate surface by rollers mounted at either side of the hardening head. (An auxiliary quenching head could also be attached *ahead* of the torch for precooling, when desired.)

The plate was supported in a shallow tank for a generous flow of cooling water underneath. Water spray, water jet or air cooling of the under-

*This paper is based in whole on wartime work for the Office of Scientific Research and Development under contract No. OEMsr-547 with Massachusetts Institute of Technology. Of the authors, E. L. Bartholomew, Jr., is assistant professor of mechanical metallurgy at Massachusetts Institute of Technology, M. S. Burton is now assistant professor of metallurgy at Cornell University, Ithaca, N. Y., and F. R. Evans (deceased) was assistant professor of mechanical engineering at Massachusetts Institute of Technology.

side could be substituted for the water bath for studying such variations. Movement and speed control of the flame and quenching heads were obtained by a variable speed motor drive.

Experimental Procedure

At the outset of the investigation it was evident that the following eight variables would have some bearing on the process:

1. Material to be hardened.
2. Flame adjustment.
3. Height of torch above plate.
4. Quench variations.
5. Precooling.
6. Underside cooling.
7. Rate of torch travel.
8. Overlap.

Preliminary experimentation showed that several of these variables had only a minor effect, so this fact, together with time limitations, indicated the advisability of simplifying the test procedure by establishing suitable conditions for some of the items listed and thereafter maintaining them constant.

Wide variations in the type and analysis of the plate material were not feasible because other interests dictated that the steels be weldable.

To obtain the greatest overall speed of hardening, the torch was operated at its maximum heat output with a neutral flame. Approximately 1200 cu.ft. per hr. of mixed oxygen and acetylene was consumed by the torch, this rate of combustion being obtained with an oxygen pressure of 8½ psi. and an acetylene pressure of 6 psi. The inner cone of the flame was ⅜ in. long with this flame adjustment, and a torch-to-plate spacing of ½ in. was found to give best results. A closer approach melted the surface layers before sufficient heat could penetrate into the body of the plate for a useful hardened layer, while a greater spacing correspondingly reduced the speed of hardening.

For most of the work, the quenching head passed cold water with a constant pressure sufficiently low to avoid splashing. Similarly, it was found convenient to maintain a constant distance between the heating torch and the quenching head.

Initial work on ½-in. plate indicated the advisability of precooling the plate by small water jets preceding the hardening torch. These are not shown in the diagram, Fig. 1.

Various methods of cooling the underside of the plate — water spray, water jet, and air cooling — were used at various stages in the experimentation. However, the circulating water bath shown in Fig. 1 was utilized in most of the work reported in this paper.

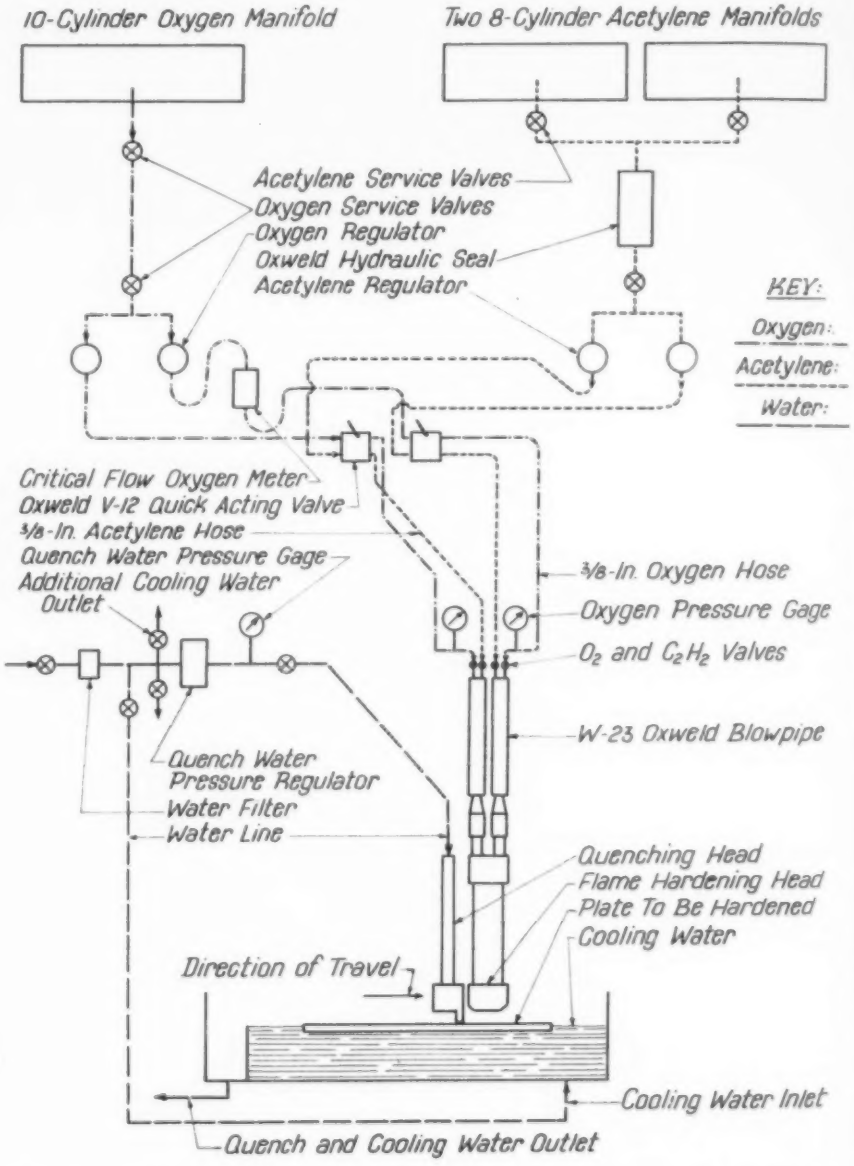


Fig. 1 — Diagram of Apparatus for Flame Hardening Experiments

Adjustment of the rate of torch travel was recognized as the most important and convenient means of controlling the depth of hardened case.

Fig. 2 — Cross Sections Through Surface Hardened 1-In. Plates, Smoothed and Etched With Ammonium Persulphate. About half size. Effect of amount of edge overlap by flame on second pass can be observed in 2-C-7 with ½-in. overlap, in 2-GL-10 with ¾-in. overlap, and in 2-R-8 with 1-in. overlap

The following speed ranges were used:

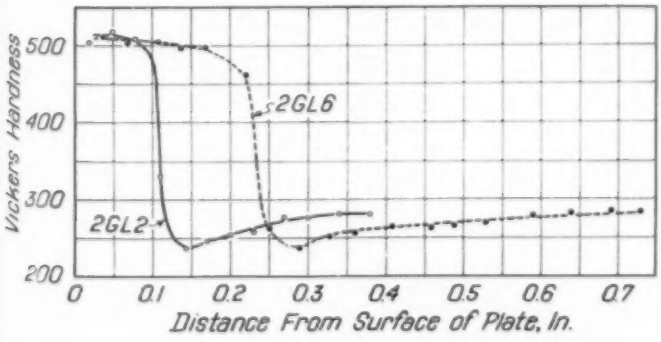
½-in. plate, 4 to 10½ in. per min.
1 -in. plate, 3 to 7¼ in.
1½-in. plate, 4 to 6½ in.

Uniformity of Hardening

Since the hardening torch was 6 in. wide, any hardened surface wider than that required successive passes of the flame. Preliminary tests were therefore performed to determine the minimum amount of overlap at the edge of a previously hardened strip for uniformity of case depth.

It was found comparatively simple to produce even case depths by the progressive flame hardening method. Typical etched cross sections of a two-pass layer on a 1-in. plate are illustrated in Fig. 2. The hardness of the resulting case was found to be as great as could be obtained by a conventional furnace heating and water quenching treatment on the same material. Hardness variations in a line normal to the surface through the hardened case to the base plate are plotted in Fig. 3 for two case depths. Good agreement was obtained between the depth as measured on the etched cross sections and that taken from the hardness surveys. It is interesting to note that the steels tested exhibit a reasonably rapid hardness transition from case to core, and that the core material immediately below the case is drawn to a

Fig. 3 — Hardness-Depth Relations in 1-In. Armor Plate, Flame Hardened to Shallow and to Deeper Cases, Respectively



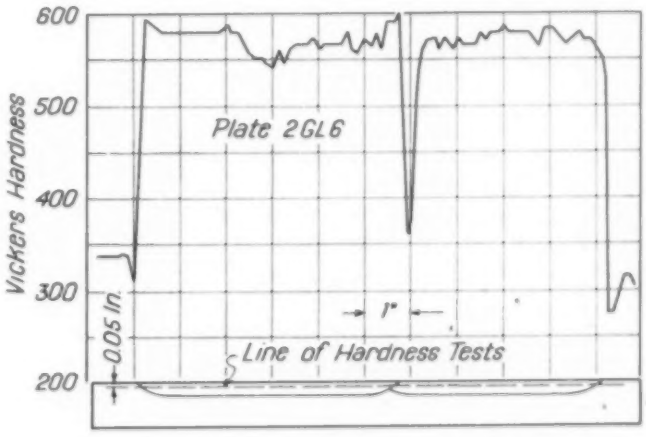


Fig. 4 — Hardness Survey 0.05 In. Below Top Surface, Showing Tempered Edges and Overlap

Fig. 5 — Irregular and Nearly Complete Penetration of Hardened Layer Resulting From Attempts to Increase Case Depth Beyond Optimum Dimension. 1-in. plate illustrated; reproduction about half size

greater degree than that to which it was originally heat treated. Comparable results were achieved on ½ and 1½-in. plate. A hardness survey parallel to and just under the top surface showed variations across the width of two adjacent hardened layers as shown in Fig. 4.

Although it was unnecessary to cool the plate ahead of the hardening torch in the heavier sections, in ½-in. plate a build-up of heat ahead of the hardening region resulted in deeper cases toward the end of each pass. This condition was minimized by cooling the upper surface of the ½-in. plate with water jets mounted on the hardening torch assembly.

It is obvious that for consistency of results the underside of the plate must be held at nearly constant temperature during the hardening process. Undercooling by water jets was attempted, but difficulties were encountered in maintaining uniform temperature where the water from adjacent jets overlapped, and this produced uneven case depths. It was felt that a high-pressure, solid cone★ water spray would eliminate this difficulty and so that method was investigated. Although it gave the most efficient cooling, the same irregularities in case depth were found at regions of water overlap. These trials led to the adoption of the circulating water bath shown in Fig. 1 for cooling the underside of the plate. Although this did not produce as drastic a chill as the water jets or spray, it gave the most uniform results.

The depth of the hardened layer was controlled by variations in the torch speed. The approximate depths of the hardened layer on the three thicknesses of plate for various speeds are indicated in Table I.

Table I — Depth of Hardened Layer Obtained With Various Rates of Torch Travel

Plate Thickness	Torch Speed	Approximate Depth of Hardening
½ in.	8¼ in. per min.	⅛ in.
½	6	¼
1	7¼	⅛
1	4¾	¼
1	3¾	3/16
1½	6¼	3/16
1½	4½	3/16

With the constant conditions of flame adjustment and height of the hardening head above the surface of the plate that were maintained, the greatest depth of hardening that could be consistently attained was ¼ in. on the ½-in. plate and 0.3 in. on the two heavier plates. Attempts to obtain thicker cases were unsuccessful due to complete heat penetration of irregular pattern on the thinnest plate, to heat penetration or surface melting on the 1-in. plate, and by surface melting alone on the heaviest plate. The uneven and sometimes nearly complete penetration when attempt-

★"Solid cone" of water is used in the sense that the entire volume of the conical jet is water, rather than a spray which has a conical shape but largely empty inside.

ing to exceed these case depths is illustrated in Fig. 5.

Although the steel near the surface of the plate was heated to a much higher temperature than it would attain in the normal hardening process in a furnace, the grain was not excessively coarsened at the surface. This was due to the short time the material remained at high temperature. A typical microsection through the surface of a flame hardened plate is shown in Fig. 6.

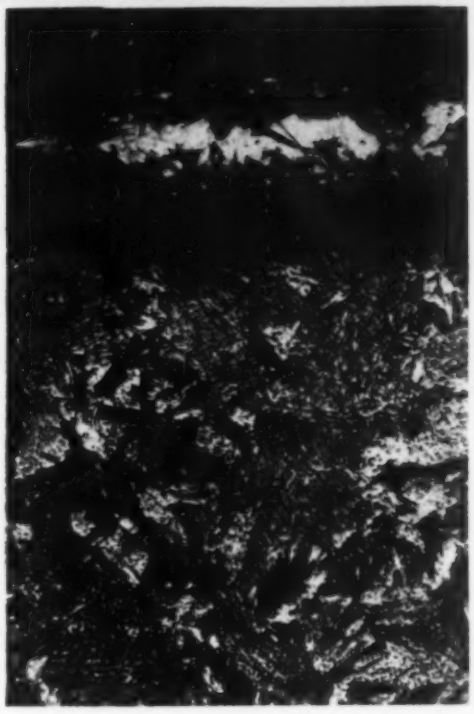


Fig. 6 — Microstructure of Case at Top Surface. Nital etch; 400 ×. Layers above martensitic body are of undetermined nature — possibly a scale effect

Several plates were hardened in which the amount of overlap between successive passes was varied. Typical examples for 1-in. plate are shown in Fig. 2. It was found that a minimum overlap of 1 in. (shown second from bottom as 2-R-8) was necessary to produce a uniform case contour. However, it was impossible to obtain uniform hardness *across* the overlapped region because of the tempering effect of the successive pass on the previously hardened case. Such a tempered region may be noted in Fig. 2 and 5 by the variations in etching response of the structure at the overlap and by the lowered hardness at that point in Fig. 4.

Distortion, Straightening and Cracking

The major problems encountered in the flame hardening of armor plate were the control of distortion and cracking, in turn produced by the drastic differential heating and cooling that is characteristic of this process.

In general, the distortion was such that the hardened layer was the concave face of the plate. This resulted from the expansion and upsetting of the heated face which, on cooling, was placed in tension. With the thicker plates of 12x18-in. size, distortion was slight, but in ½-in. plate it became serious enough to interfere with the proper operation of the equipment. To overcome most of this distortion, the thin plate was bolted to a rigid frame during the hardening process.

Even with 1-in. plates, the over-all distortion when surface areas of 36x36 in. were hardened became so great that straightening was necessary. Such straightening often cracked the hardened layer. Maximum distortion in 1x36x36-in. plate is illustrated in Fig. 7. Attempts to overcome distortion by prebending the plate were unsuccessful, for differences in the residual stress condition from one plate to the next produced an unpredictable movement during hardening and prevented exact calculation of proper amount of prebending.

Summary

It is a comparatively simple matter to produce hardened layers of appreciable thickness on steel by the flame hardening method, as has been previously shown by the successful application of this process to the surface hardening of gear teeth, valve stem ends, and many other machine parts. However, when the width of the required case is greater than can be hardened by a single pass of the torch, and the mass or area is such that an oscillating progress of the flame is impracticable, a uniform metallurgical structure cannot be obtained across the overlap region. In all instances a softened edge will exist in the prior passes due to the reheating effect of the subsequent passes. This extends throughout the previously hardened surface. Although distortion may be negligible where the case is shallow and where the unhardened metal is sufficiently rigid, it may readily become excessive in the flame hardening of flat plates of considerable area.

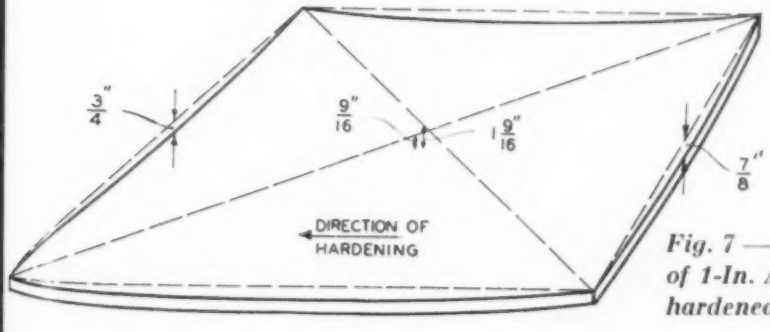


Fig. 7 — Maximum Distortion in a 36x36-In. Piece of 1-In. Armor Plate After Flame Hardening. The hardened surface is up and has become concave

A New Batch-Type Gas Cyaniding Furnace

By J. A. Dow
President, Dow Furnace Co.
Detroit

Advantages of the continuous gas cyaniding furnace, at less first cost for equipment, are secured in a batch-type furnace with work contained in shallow boxes charged and discharged through a vestibule at one end. Innovations are in methods of rapid heating of cold charge by an interchange of heat with an "accumulator" built into the furnace walls, the continuous adjustment of gas atmosphere to the work temperature by an ingenious placement of catalyst tubes, and oil quenching by a down-rush of a cascade of liquid.

CARBO-NITRIDING, or cyaniding with gas, has now become well established as a low cost substitute for the traditional cyanide pot, and bids fair to replace it in a few years as the established method of obtaining a thin, file-hard case on parts made of low-carbon steel. Some 40 or more continuous furnaces are daily casehardening all types of parts normally cyanided, with a direct cost (including labor) of little more than the cost of the cyanide drag-out of liquid cyaniding. Total costs of less than ½¢ per lb. are not uncommon.

In contrast to what may be called the wet method, all gas cyanided parts are quenched in oil, unless core hardness specification requires the faster quenching rate of water. For this reason distortion is much reduced, and local hardening with its attendant high labor cost is rarely found necessary. This feature of the gas process was ably presented by Walter H. Holcroft in his article in September's *Metal Progress*. He pointed out that the advantage lies in being able to vary the carbon and nitrogen contents of the case independently. Nitrogen, acting like other well-known alloying elements of steel, reduces the critical quenching speed, and can readily be varied in the gas process to form a quenched microstructure of any desired relative content of martensite and austenite.

The *continuous* furnace is, however, limited in application to relatively high production of like parts, or parts requiring the same temperature of treatment and case depth. Industry's need for a batch-type furnace, with its lower initial cost and greater adaptability in operation, has long been recognized by all furnace engineers, but attempts to pattern a lower capacity batch furnace after the continuous furnace design have invariably led to a furnace too costly for its output. This high cost seemed unavoidable, due to the expensive mechanisms required for heating and sealing the furnace, and handling the work, as well as to the cost of the very necessary gas generator.

A three-fold development program, undertaken some years ago, has now resulted in a new type of furnace, well tested by eight months of continuous, trouble-free operation by one of the leading automobile makers. The furnace incorporates innovations in heating and quenching and a marked simplification of the gas generator. It has operating costs that compare very favorably with the continuous furnace, and the adaptability inherent to the batch-type. The three major developments are described in the following paragraphs.

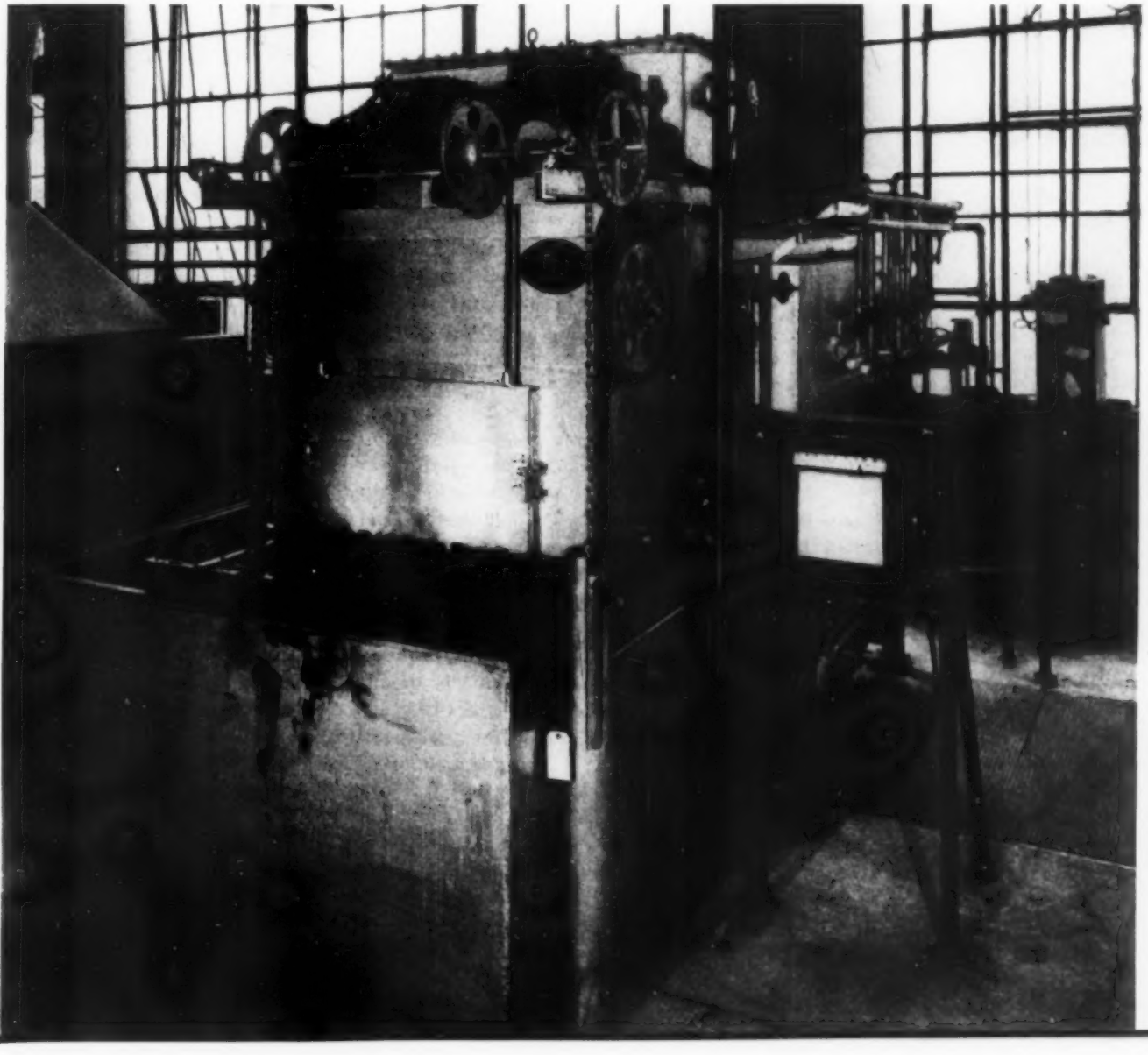
Higher Speed Heating — Radiation from electric elements or gas-fired radiant tubes was quickly discarded as the prime method of heat transfer, since it involved single layer heating with two attendant drawbacks — namely, continuous attention of the operator, and a very large furnace for case depths of more than 0.001 or 0.002 in. Convection heating, as conventionally

done with atmospheres circulating from external heater to furnace chamber, was far from satisfactory. This is due to the wide variation in temperature normally existing in different parts of the load when approaching control temperature, and to the long time interval between the first and last pieces of the load reaching control temperature. To properly evaluate this in light case work, it should be recognized that a case of 0.007 in. can be produced in 15 min. at 1550° F. A variation in time at heat of even this small amount can therefore cause an excessive nonuniformity of case. Convection heating was, however, chosen over radiation as holding the greater promise for improvement.

An analysis of convection heating furnaces showed that containers of small cross section and relatively great depth, when filled with small parts, offered an excessive resistance to a high volume of air flow. Some considerable improvement in heating characteristics was obtained by greatly increasing the cross-sectional area of the work containers, and at the same time reducing their depth. This improvement did not, however, prove adequate, although it did permit a lower fan speed, and this has saved much maintenance expense. Later work provided a simple and very effective solution.

It was reasoned a high temperature gradient through a load was inconsequential below the critical of the steel, provided the gradient could be reduced in the later stages of the heating cycle and before the first of the parts reached case-forming temperature. A very, very high heat input in the early part of the heating cycle, followed by a reduced heat input toward the end, would produce this pattern of temperature gradient with no sacrifice in over-all heating time, but this seemed to indicate that the number of heating elements or radiant tubes must be largely increased in number.

Fig. 1 — Batch-Type Carbo-Nitriding Furnace, Viewed From Charging (and Quenching) End. Unique features include atmosphere-generating tubes within the radiant tubes that heat the furnace



To accomplish this desired result and by a much simpler mechanism, a "heat capacitor" was developed, in the form of refractory masses of high specific heat surrounding the radiant tubes. When a fresh load of work is put into a hot furnace, this heat capacitor gives off heat to the circulating gases at a very rapid rate, augmenting that given off by the radiant tubes. As the stock approaches its critical temperature, however, the heat capacitor has been cooled to a point where it actually becomes a heat absorber, and stores a large part of the heat produced by the radiant tubes whose temperature is maintained at a higher level by the action of proper automatic control mechanisms. The heat absorbing mass receives this heat through direct radiation, thereby reducing the amount of heat which must be handled by the circulating gases. Through this action of the heat capacitor, the gradient in temperature through the load, as it approaches control temperature, is less than one tenth that of the early heating period — in fact, it is of such a low value that a case variation of ±0.001 in. is found on parts of a load quenched only 5 min. after the control thermocouple indicates control temperature is reached.

Fig. 2 — Group of Small Parts, Gas Cyanided

Quenching — The heating of bulk loaded parts adequately solved, the problem of quenching this mass of parts came to a head. A series of tests was devised in which S.A.E. 1335 bolts were imbedded in a load of ¼-in. diameter button headed rivets, ½ in. long. The box was fitted with a wire screen bottom, and was arranged to fit a quenching elevator sealed by leather bands in a small quench tank. As the elevator dropped, it acted as a piston forcing oil up through the box of parts resting on it. On the first test, the bolts and rivets were floated clear out of the box!

The final design of quench tank uses a propeller driving the oil past a partition so it takes a closed circulating path; thus the oil is forcibly drawn down *through* the work baskets in extremely high volume. This is a far cry from the more or less uncontrolled agitation of a bath induced by a propeller in an open tank, where no pressure differential across the load can be developed.

Ample experience with this new design proves that loads of densely packed parts of S.A.E. 1335 steel can be oil quenched to a core hardness within the range of 2.60 to 2.70 mm. impression diameter (Brinell 555 to 514), the range regularly obtained on the same part quenched singly into a deep oil tank from a recently built conveyer furnace.

Gas Generator

Adequate control of gas carburizing or gas cyaniding it based on the premise of an adequate supply of uniform quality generator gas of American Gas Assoc.'s Class 302.* Unless the carbon dioxide and moisture content of this gas is very low and constant, a variation in case quality is unavoidable. This gas is conveniently made in a gas generator operating at a temperature of at least 1750° F. — normally a separate furnace structure having its own heating equipment and temperature controls, and involving considerable cost of manufacture.

It was discovered that if the quantity of gas taken from such a gas generator were reduced, its operating temperature could be reduced, but it must at all times be considerably hotter than the furnace in which its gas is to be used if a gas of adequate quality is to be produced. (By "adequate quality" is meant the negative attribute of being powerless to scale or decarburize the steel at working temperatures, and the positive attribute of being a proper carrier of carbon and nitrogen to

*An endothermic base, completely reacted gas-air mixture, with formation of water vapor held to a minimum by the use of a catalyst in the reactor. See *Metal Progress* Data Sheet, August 1947, p. 256-B.

the steel's surface.) The gas generator of the furnace, whose photograph is reproduced as Fig. 1, consists of six tubes of small diameter, inside the burner leg of each of the six heating tubes. The generator tubes are concentric with the larger heating tubes and extend through them. They are welded to the return-bend elbows, and are free to expand through gasketed joints in the burner head. These generator tubes are filled with a conventional type of catalyst and are fed with the conventional mixtures of air and natural gas or propane.

These inner atmosphere-generator tubes extract heat from the gas burning in the annular combustion space at a much faster rate than required for the endothermic reactions going on within them, and so become considerably hotter than the exterior surfaces of the radiant tubes which, in turn, operate hotter than the furnace at all times. (An unconventional burner design and system of temperature control maintains a high temperature difference between the generator tube and the furnace on low firing, without in turn causing this difference to be excessive on high setting.) On account of this continuous temperature differential between gas generator and furnace load, the gas atmosphere produced is automatically varied in $CO:CO_2:H_2:H_2O:CH_4$ equilibrium so it has "adequate quality" — in the sense defined above — for medium-high carbon steel throughout the entire heating and carbo-nitriding cycle.

A further gain is obtained from the circumstance that such a concentric arrangement increases the heat extraction rate from the burning gas, and permits operation of the tubes at approximately 50% greater capacity than the usual practice, with no sacrifice in efficiency of combustion, as proven by metering the gas used.

Furnace Operation

The photograph on page 985 is of the first production furnace embodying the developments described above. The furnace was installed in an automotive plant in Michigan in April 1947, and has been in continuous operation since then, except for a period of one month, when a sudden appearance of sulphur in the natural gas necessitated the installation of a bank of propane cylinders for the gas generator and carburizing addition. Maintenance has been negligible.

Four trays and work boxes compose a furnace load. Each container is approximately 12x18x12 in. high. A 500-lb. net load of anything from nuts to stampings is heated to control temperature in 36 min., and is held at heat from 5 min. to 1 hr., depending on the case depth specified. The loading and unloading time is 8 to 10 min. Two trays are quenched at a time through the vestibule to be observed under the control machinery at the front of the furnace. The vestibule's outer door is at the end of the short rails on the loading conveyer; the vestibule's inner door is a heavy refractory slab which is lifted into the housing seen immediately behind the control machinery. The floor of this vestibule is the platform of an elevator, and the hot load is lowered into the quenching oil and a powerful rush of oil drawn through by submerged pump (as indicated in the previous general description). The hot parts thus do not contact air and are gray in color after quenching.

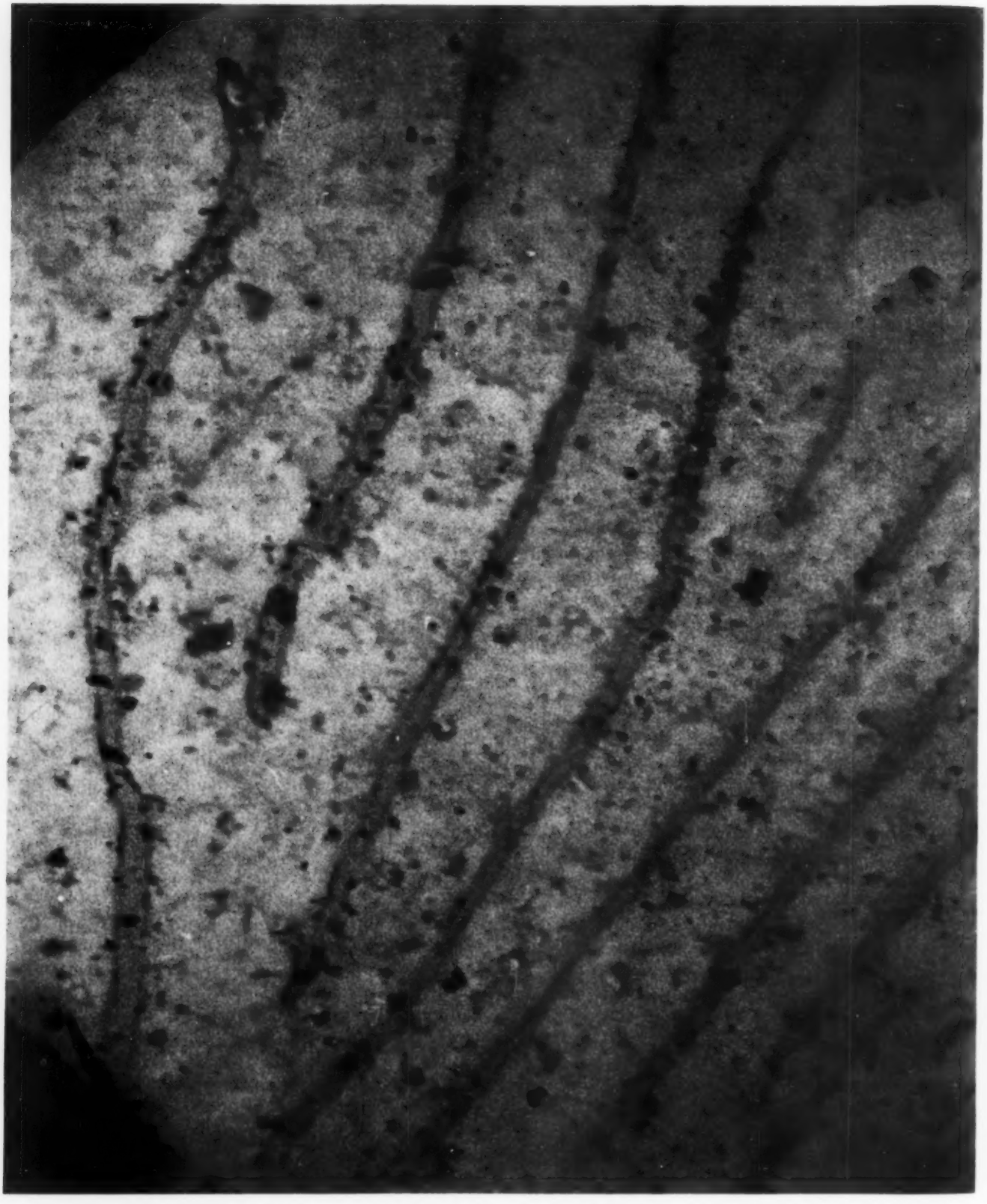
Both the inner and outer vestibule doors are opened momentarily for loading, and the trays are loaded across the quenching elevator, whose platform is equipped with gravity rolls. The elevator and inner door are motor operated.

Companion wash machines and tempering furnaces have been designed for handling parts without emptying them from the hardening furnace boxes.

The commonly specified 0.003-in. cyanided case is formed in about 10 min. at heat, giving a total heating and holding time of 46 min. for 500 lb. of parts, and a floor-to-floor time of 56 min. The operator is required at the furnace only about 10 min. of every hour, leaving 50 min. to load and unload containers and attend to other furnaces. With half of a man's time allotted to the furnace, the direct operating cost of the load described, including labor, fuel, generator gas, carburizing addition, ammonia, electricity and a generous allowance for maintenance is between $0.003 and $0.004 per lb. treated. (It is recognized that furnaces can rarely be operated continuously at rated capacity, and that average costs over a long period will be somewhat higher.)

Since water quenching is unnecessary, distortion is greatly reduced. In the installation photographed, parts, which in previous practice were locally treated in liquid cyanide and straightened after quenching, are now treated all over and the straightening is eliminated. The entire quantity of parts previously treated in two electrically heated cyanide pots is now being handled by this furnace, and there is considerable excess capacity which has been assigned to parts requiring a case depth of approximately 0.040 in. With a slight ammonia addition to the carburizing gas, these deeper cased parts also quench out in oil.

Summarizing, the furnace has completely eliminated liquid bath heat treatment of production parts in this large automotive plant, and is being found to be a cost saver on an ever increasing list of parts.



The First Successful Photograph of Steel Surface Made With an Electron Microscope

Pearlite at 24,000 ×. Photograph made in 1940 in V. K. Zworykin's laboratory (Radio Corp. of America) by Robert F. Mehl, E. G. Ramberg and R. F. Baker. Single replica method, using the plastic "Vinylite"

New Applications of X-Ray and Electron Beams to Metal Research

By Ben H. Alexander
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METALLURGISTS have almost always been limited in their study of phase changes by the necessity of having to observe at room temperature what they hope was the structure that existed when the metal was hot. That is said with no disparagement of the important data collected by dilatometers and by recording the electrical and magnetic characteristics of metals at high temperatures. The limitations of those methods serve to emphasize the importance of X-ray and electron diffraction equipment which can be used when the sample under observation is at any desired temperature, hot or cold. Hence the interest residing in a group of papers read before the Fifth Annual Pittsburgh Conference on X-Ray and Electron Diffraction, which was held in the luxurious Mellon Institute, Nov. 7 and 8.

J. H. Kittel of the N.A.C.A. Aircraft Engine Research Laboratory, Cleveland, presented the results of an X-ray study comparing the crystal structure of 10 wrought heat resisting alloys at elevated temperatures with their crystal structures at room temperature. The alloys* studied were S-816, S-590, Hastelloy B, N-155, 16-25-6, K-42-B, Type 347 stainless, Nimonic 80, Inconel X, and 19-9 W-Mo.

He determined the crystal structure of the predominant phase at room temperature and after holding 1 hr. at 1200, 1500 and 1800° F. The crystal structure at the elevated temperatures was determined by using a Geiger counter and X-ray spectrometer which had been modified for high-temperature diffraction studies. Of the 10 alloys studied, only one, the alloy 19-9 W-Mo, showed evidence of a phase change. This alloy, which consisted of a two-phase mixture of body-centered and face-centered cubic structures at low temperatures, began to transform to a single-phase face-centered cubic structure between 1400 and 1450° F.; the transformation was completed between 1450 and 1500° F.

The other nine alloys retained their room-temperature structures up to 1800° F. Thermal dilation studies on the same alloys, including 19-9 W-Mo, gave no indication of phase transformations. However, in the discussion it was suggested that the short holding time (1 hr.) at temperature is often insufficient for transformation to occur in these alloys even if the room-temperature structures were unstable at the higher temperatures.

Another paper, by J. W. Hickman, E. A. Gulbransen and R. J. Bertl, of Westinghouse Research Laboratories, enumerated the many problems that arise in the design and construction of high-temperature X-ray and electron diffraction cameras. The characteristics and merits of various materials that can be used for heater supports, heater elements, radiation shields, windows, sample containers, and assembly parts were described, as well as methods of arranging and moving the sample, film, and thermocouples in a vacuum camera.

J. W. Edwards, R. Speiser and H. L. Johnston, of the Cyrogenic Laboratory, Department of Chemistry, Ohio State University, reported on a

*S-816 is nominally 20% Cr, 20% Ni, 43% Co, 4% each Mo, W, Cb and Fe, 0.40% C.

S-590 is 20% each Cr, Ni and Co, 4% each Mo, W, Cb, 25% Fe, 0.40% C.

Hastelloy B is 28% Mo, 5% Fe, 66% Ni, 0.10% C.

N-155 is 20% Cr, 3% Mo, 2% W, 20% Ni, 20% Co, 1% Cb, 0.15% each C and N.

16-25-6 Cr-Ni-Mo plus 0.10% C, 0.15% N, bal. Fe.

K-42-B is 42% Ni, 22% Co, 18% Cr, 2% Ti, bal. Fe.

Type 347 stainless steel is 18% Cr, 10% Ni, 1% Cb.

Nimonic 80 is 75% Ni, 21% Cr, 2.5% Ti, 0.6% each Al and Fe, 0.05% C.

Inconel X is 73% Ni, 15% Cr, 7% Fe, 2.5% Ti, 1.0% Cb, 0.6% each Mn, Si, Al, 0.04% C.

19-9 W-Mo is 19 Cr, 9 Ni plus 1.25% W, 0.40% each Mo, Cb, Ti, 0.40% C, bal. Fe.

high-temperature X-ray powder diffraction camera which uses high frequency induction heating. In this camera the specimen is placed between two cylindrical heating elements, ½ in. high by ¾ in. diameter, closed on one end. These elements, which may be made of any convenient refractory conductor such as molybdenum or carbon, are heated by current induced by a small coil of water-cooled copper tubing. Preliminary experiments have shown that this camera will operate successfully at temperatures up to 3600° F., and the authors expect to operate it at much higher temperatures. The temperature is controlled by the energy input to the induction coil, and temperature is measured with an optical pyrometer.

Nature of Oxide Surface Films

One of the papers most interesting to metallurgists was by J. W. Hickman, also of the Westinghouse Research Laboratories — a study of oxide films formed on copper-nickel alloys at elevated temperatures. A high temperature electron diffraction camera was designed for determining the compound existing on the extreme outer surface of the specimen as it was being oxidized at high temperatures, and without first cooling to room temperature. In the copper-nickel system it was found that copper oxide forms the outer layer at lower temperatures, while nickel oxide occurs on all the alloys above 1300° F. Nothing but the simple oxides of copper and nickel was observed (that is, Cu_2O and NiO).

Dr. Hickman said that his results support the contention that the type of oxide formed on the outer surface of the oxide layer is determined by such factors as the rates of formation and diffusion of metallic ions from the metal through the oxide layer. Thus he says that at low temperatures copper ions have a greater tendency to form and diffuse to the surface, while at higher temperatures nickel ions reach the surface, hence the relative thermodynamic stability of the two oxides does not determine which one will appear. His studies showed further that there was apparently no structural change in the oxide layer at the composition which corresponds to its acquisition of a passive state with respect to wet corrosion.

The interpretation and use of electron diffraction studies on metals at high temperatures were also discussed by E. A. Gulbransen of the Westinghouse Research Laboratories, who has been a pioneer in the field of oxidation of metals and alloys. He described the three laws of oxidation (linear, parabolic and logarithmic) and discussed the general theory of the oxidation process. He pointed out that the crystal structures of the oxide film are intimately related to the mechanism of the oxidation reaction. That there is a necessity for studies "at temperature" was shown by his findings that sometimes the type of oxide existing at high temperatures is not retained upon cooling or quenching in inert gases to room temperature. His theory is as previously stated by Dr. Hickman — that the reaction rate is controlled by such factors as the rates of formation and diffusion of metallic ions through the oxide layer.

Other papers referring to metallographic techniques and physico-metallurgical theory can only be briefly noted.

Those who are interested in extremely fine particle sizes will be intrigued by the application of the Geiger counter X-ray spectrometer described by L. E. Alexander and E. Kummer, of the Mellon Institute. Their method consists in a measurement of line broadening wherein a correction is made for broadening due to other causes than particle size. The method is applicable for sizes up to 400 Å, but is not accurate for larger particles.

A. H. Geisler and J. K. Hill, of the General Electric Research Laboratory, described a new method of analyzing the two-dimensional diffraction effects from aged alloys. Their method is similar to the oscillating crystal method for three-dimensional diffraction in that a single crystal and the monochromatic component of radiation are used to obtain a reciprocal lattice plot of the structure. In the authors' new method, however, the crystal is held stationary and a series of exposures is made with the crystal moved an increment of 5° or less between exposures. The loci of the Kα reflections along the streaks are plotted in the reciprocal lattice to give the rod-like areas of reflection characteristic of two-dimensional diffraction from the platelets of precipitate that are parallel to various planes of the matrix crystal. If the precipitate particles are too small in two dimensions to cause diffraction, the reciprocal lattice plot gives a plane rather than a rod. The authors have obtained some results that suggest this one-dimensional diffraction. Their new method of analysis has been found to be superior in some cases to the older method which involves a stereographic plot of the streaks formed by white radiation in Laue patterns, and thus should prove to be a valuable aid in establishing the true mechanism of precipitation and an acceptable theory of age hardening.

A. H. Geisler (with J. K. Hill and J. B. Newkirk of the General Electric Research Laboratory) presented another paper in which he described an adaptation of the Lonsdale technique of divergent beam X-ray photography. *(Cont. on p. 1024)*

A New Structural Diagram for Cast Iron

By H. Laplanche
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Maurer's structural diagram for cast iron still appears in today's metallurgical literature despite the fact (admitted by the originator shortly after its first publication) that it applies only to a single size test piece and cooling rate. His original text is quoted to show that the diagram was based on assumptions rather than information. The present author presents a new structural diagram conforming to present-day foundry conditions, relating the silicon, carbon, and cooling rate to the resulting microstructure.

IT IS surprising to find in the new "Handbook of Cupola Operation", published by the American Foundrymen's Assoc. (1946), the original Maurer's diagram which purports to show the micrographic structure of the matrix in cast irons as it varies with total carbon and silicon contents. This diagram is a typical example of the mistake which can be made when an experimental question is resolved on the basis of an idea adopted before starting the work.

It is strange, yet true, that the text which was accompanying the original diagram seems to be as unknown as the diagram itself is universally known. Therefore, it is worth while to quote Maurer's original note, published in *Kruppsche Monatshefte*, July 1924, p. 115. Maurer writes:

"In his diagrams for alloy steels, Guillet had drawn straight lines having their intersection at the point representing 1.65% carbon. A similar intersection should be placed on the axis representing carbon content in the cast iron diagram. For that reason, I have chosen the eutectic point at 4.30%. [*A*, Fig. 1.] On the horizontal axis representing silicon content, I have placed *B* at 2% Si, because my tests on the graphitic fracture of steels had proved that steels with 2% Si could be cast with a carbon content as high as 1% without any precipitation of graphite.

"I have taken the point 7% Si [*C*, Fig. 1] from Guillet's diagram of silicon steels. In drawing the straight lines *AB* and *AC*, I obtain the three areas corresponding respectively to white irons, pearlitic irons and ferritic irons.

"To obtain the transition areas *IIa* and *IIb*, *B* was projected upward to *B'*, to intersect the horizontal line representing 1.70% C, because that carbon content must be considered as the boundary between steels and cast irons. Similarly, *D* was projected downward to *D'* on the silicon axis. Then, we have drawn *AB'* and *AD'*, and obtained the transition areas *IIa* and *IIb*, corresponding respectively to mottled irons and pearlitic-ferritic irons."

All foundrymen know and use this diagram because it is extremely simple, easy to use, and because everybody thought that it was the result of a great amount of experience and tests.

However, almost as soon as it was published, this diagram was found to be wrong by its author, and a new one was published in 1927 by Maurer and Holtzhausen. Many other authors (Coyle, Greiner and Klingenstein) tried to modify the structural diagram for irons, but they kept a diagram with straight and concurrent lines.

Maurer's diagram is marred by two fundamental mistakes:

The first error is to draw a single diagram for all cases, thus eliminating a main factor, namely, the cooling rate of the metal in the mold. (Guillet had made the same error in his famous diagrams for alloy steels, and replaced a problem of kinetics by a problem of statics.) Every foundry metallurgist knows that the structure of a cast

iron, for a given chemical composition, depends upon the temperature-time cooling curve. In his second paper (1927), Maurer indicates, for the first time, that his diagram should be applied only to 30-mm. test bars (about 1¼ in. diameter), and that the boundary lines are displaced to the left by slower cooling, and to the right by more rapid cooling.

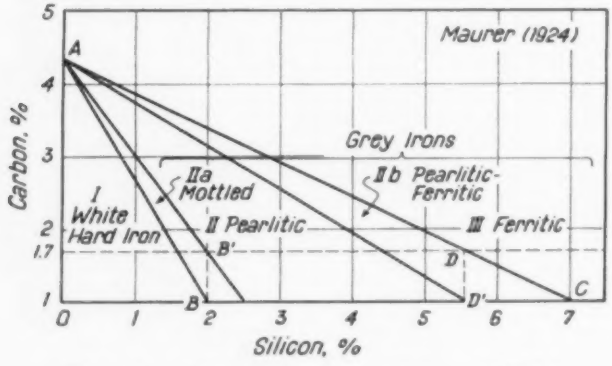


Fig. 1 — Maurer's Diagram (1924) Showing the Construction Given by Him

As a rough and first approximation, the chemical factors may be reduced to two (the carbon and silicon content, thus eliminating phosphorus, sulphur, manganese and gases). But it is impossible to eliminate the factors of temperature (θ) and time (t). The latter two may be reduced to one if we assume that they are connected by a simple relation such as

$$\frac{d\theta}{dt} = V \text{ (average rate of cooling)}.$$

The second error is to assume that boundary lines are straight. It is always allowable, with a view of simplification, to replace a curve by its chord or its tangent in a small arc (the extent of which depends upon the curvature), but it is an important mistake to extrapolate that straight line very far. Even when an experimental line *seems* to be a straight line, it is necessary to examine the situation before extrapolating. Sometimes, this operation is an indirect way of proving that a linear relation does *not* persist.

In Maurer's diagram, it is obvious that the straight lines are inadmissible, for they lead to the result that all irons having more than 4.30% C have invariably a ferritic matrix, and that the structure of all irons having close to 4.30% C is indeterminate.

Besides, if Maurer's diagram were right, irons containing 0.50% Si with increasing amounts of total carbon would show all the different structures of the matrix. With 0.50% Si and 4.40% C, we should see a ferritic matrix, and every foundry metallurgist knows that, in fact, this is not true.

Norbury and, later, Uhlitzsch and Weichelt have given new structural diagrams for irons and the boundaries of the areas are curved lines (Fig. 2). Each diagram is, in fact, a cross section of a three-dimensional diagram, with axes of %C, %Si and $\frac{d\theta}{dt} = V$, and therefore corresponds to a fixed diameter of test bar, cast under given conditions.

The results of the present writer's tests on the chemical composition of the carbides contained in common white irons, their solubility in austenite, and their decomposition during solidification have led him to a formula giving the tendency to graphitization versus %C and %Si, for a fixed rate of cooling.

For instance, with cylindrical test bars 30 mm. in diameter, cast in ordinary foundry sand, we may write

$$K = \frac{4 \times Si}{3}\left(1 - \frac{5}{3C + Si}\right)$$

All the irons giving the same value for the coefficient K will have the same structure after cooling in the same conditions. Curves for K = 0.5, K = 1, K = 2 and so on are easy to draw, and their remarkable analogy with Uhlitzsch's curves can be noticed. (See the data sheet on page 992-B.)

Besides, one can draw on the same diagram

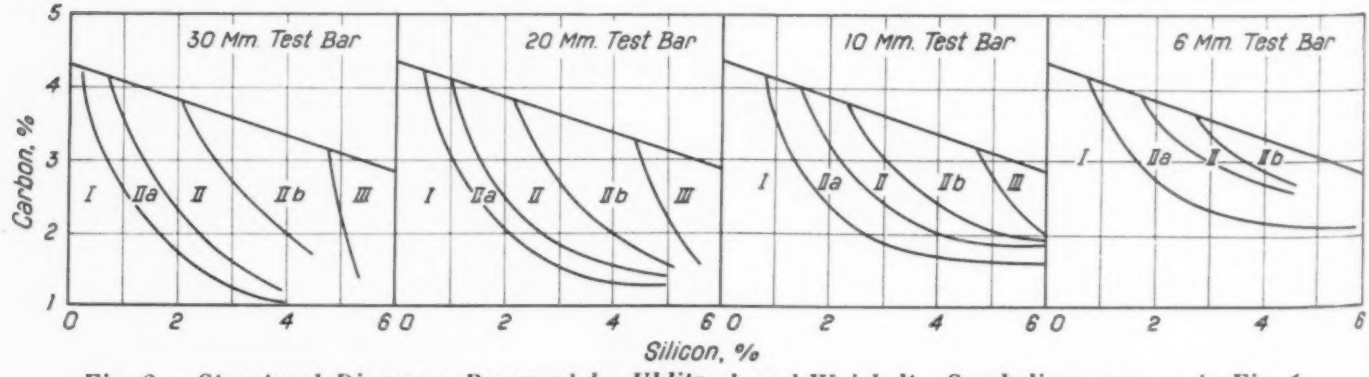
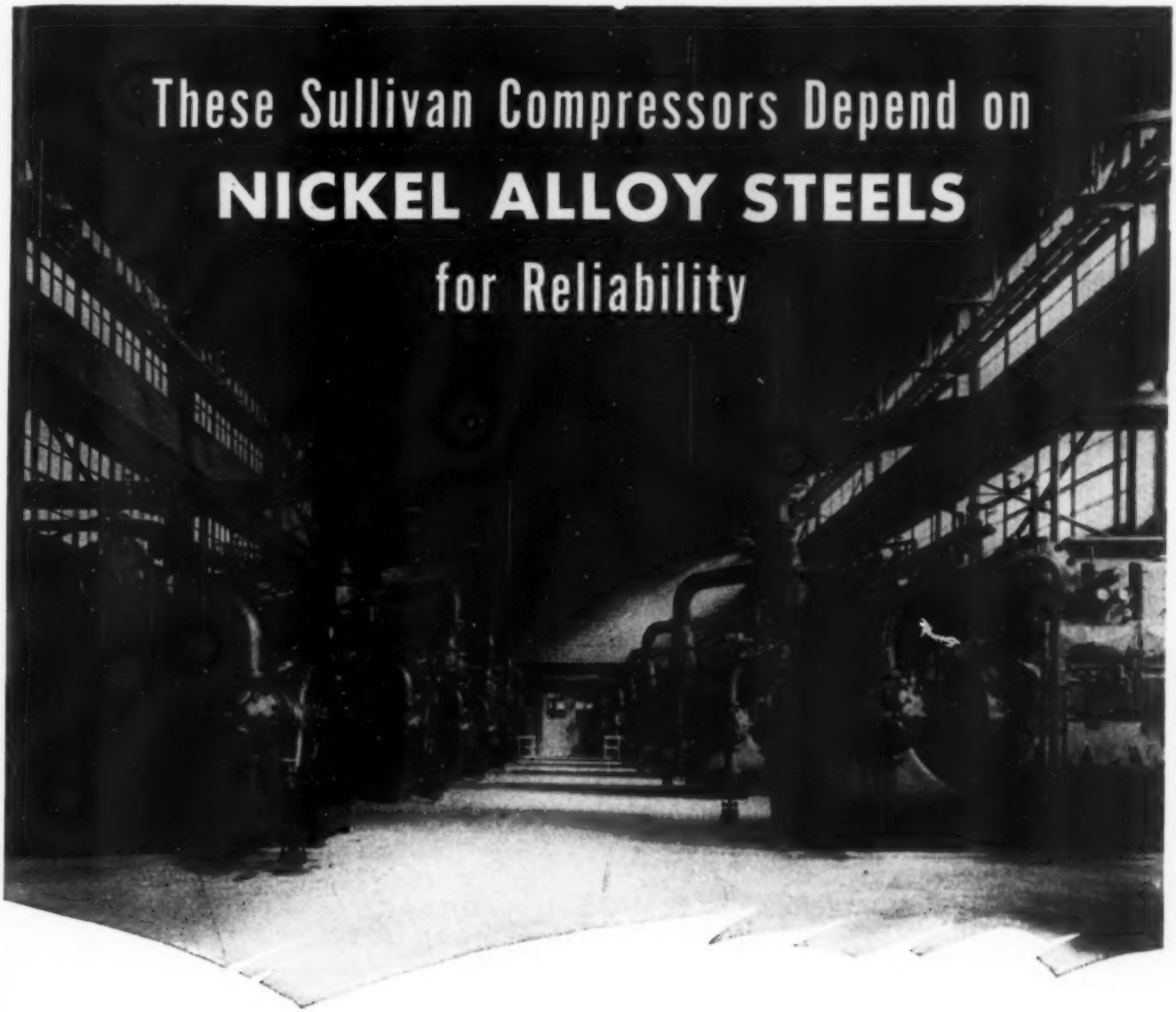


Fig. 2 — Structural Diagrams Proposed by Uhlitzsch and Weichelt. Symbolism same as in Fig. 1.



These compressors, built by the Sullivan Division of Joy Manufacturing Company, are a good example of the way Nickel alloy steels help make equipment longer-lasting and more dependable.

Crankshafts in these units are of large diameter, and accordingly, a Nickel-chromium-molybdenum steel, Type 4340, is used to secure good depth hardening. This steel makes possible heat treated forgings that provide ample strength, good ductility and ready machinability.

Cross head pins and other stressed parts are produced in a case hardening Nickel-molybdenum steel, Type 4615. This steel responds readily with minimum distortion to simple quenching treatments, and affords a wear resistant, non-spalling surface supported by a tough core that enables the part to resist shocks and overloads.

The excellent mechanical and fabricating properties of Nickel alloy steels provide a practical answer to problems of low-cost, trouble-free operation of equipment.

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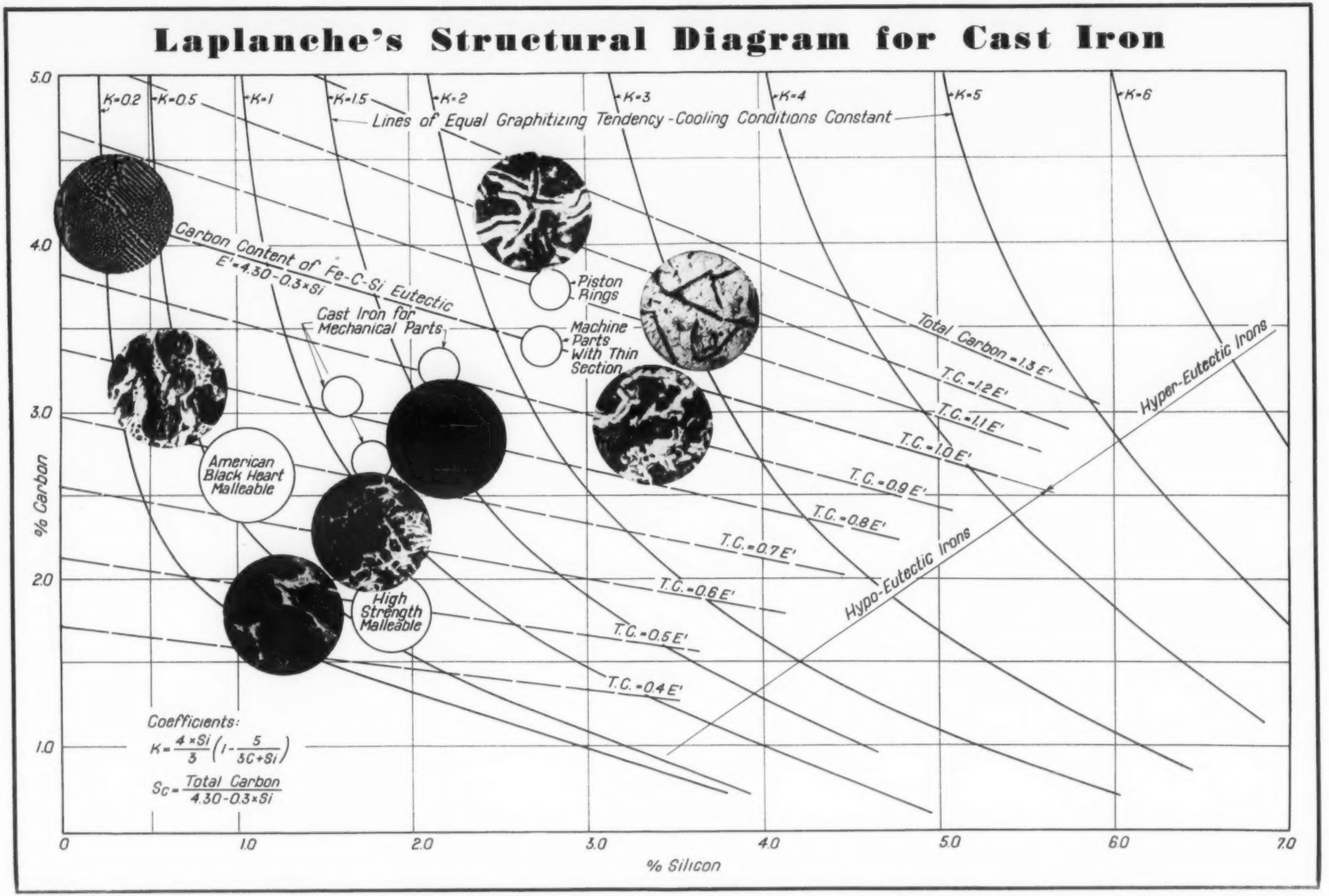
Laplanche's Structural Diagram for Cast Iron



the straight lines corresponding to the carbon content of the Fe-C-Si eutectic for each value of Si content, according to the formula (given on p. 394 of "Handbook of Cupola Operation"):

$$E' = 4.30 - 0.3 \times Si$$

We thus obtain the data sheet where each straight line corresponds to a given value of the ratio

$$S_c = \frac{\text{Total Carbon}}{4.30 - 0.3 \times Si}$$

On this diagram, all cast irons are determined by two coefficients S_c and K. Coefficient S_c is determined by the desired position of the alloy as to the eutectic $E' = 4.30 - 0.3 \times Si\%$ (that is, hypoeutectic or hypereutectic alloy). Coefficient K is determined by the desired structure (white, mottled, entirely pearlitic, pearlitic-ferritic, or entirely ferritic matrix).

The intersection of an S_c straight line and a K curved line gives C and Si contents which must be adopted for the desired structure. For instance, the data sheet gives a circle noting the chemical composition (2.6% C, 1.0% Si) of hard irons for American black-heart malleable and another circle gives the composition (1.8% C, 1.8% Si) of hard irons for high strength black-heart malleable. Three smaller circles give compositions of cast iron machine parts, another for pieces with thin sections, and still another notes the composition of cast iron piston rings (cast in groups).

Some photomicrographs placed on the diagram show the structure obtained with the corresponding composition and cooling rate.

A Punch Card Filing System for Metallurgical Literature

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ARE YOU A "Tiotots" (throw-it-on-top-of-the-stack) or a "LOC" (Library-of-Congress) type when it comes to filing reports, literature references, preprints, and so on? Probably you are somewhere between these two extremes, recognizing the *ease* of operation of the Tiotots' method yet admiring, as you would a distant star, the *efficacy* of the LOC's unapproachable system. This article describes a filing method, based on punch cards, Fig. 1, that permits the simultaneous attainment, not only of ease and efficacy, but also of other desirable features of a practical filing system. This may strike you as being almost too good to be true!

In spite of the availability of such guides to current technical literature as the ⊖'s excellent annotations published in *Metals Review*, undoubtedly most metallurgists find it necessary to have a personal filing system. In this file they may record references to bordering fields, such as physical chemistry, to company reports, to correspondence, or to articles of special interest.

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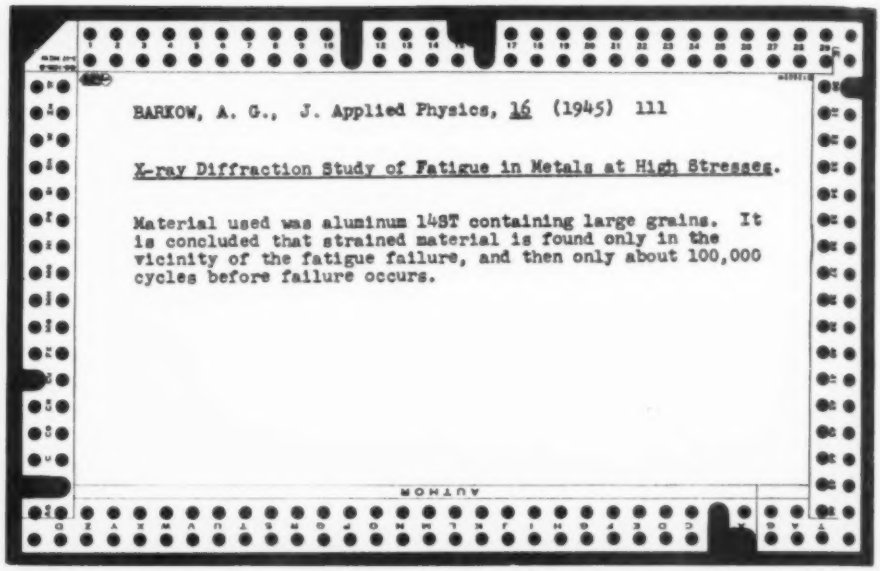
The following persons have contributed ideas, primarily in connection with the metallurgical general file: W. C. Dunlap, Jr., J. F. Eckel, D. L. Martin, and Lyall Zickrick of the General Electric Co.; M. F. Hawkes, F. N. Rhines, and J. T. Ransom of the Metals Research Laboratory, Carnegie Institute of Technology; H. H. Uhlig of the Massachusetts Institute of Technology; H. W. Gillett, R. H. Hopp, and S. A. Hoyt of Battelle Memorial Institute; W. F. Hess of Rensselaer Polytechnic Institute; M. E. Merchant of the Cincinnati Milling Machine Co.

Steel Progress Data Sheet; December 1947; Page 992-B

Subject index at top and right


BARKOW, A. G., J. Applied Physics, 16 (1945) 111
X-ray Diffraction Study of Fatigue in Metals at High Stresses.
Material used was aluminum 14ST containing large grains. It is concluded that strained material is found only in the vicinity of the fatigue failure, and then only about 100,000 cycles before failure occurs.
Alloy index at left edge
AUTHOR

Author index at bottom

Fig. 1 — Reproduction of a 5x8-In. Punch Card Containing a Brief Abstract of a Technical Article, Properly Slotted for Sorting With a Needle, as Shown in Fig. 2

Ordinary 3x5-in. cards are employed, but the difficulties of cross-referencing are frequently disastrous. Should a given reference be listed under the author (or authors!), under one or more subject matters, or under the alloy in question? It would take a trained librarian to answer such a question.

Punch cards materially reduce the cross-referencing problem in the following manner: They are used in the same way as conventional filing cards, since the pertinent information is recorded. However, cross-indexing is accomplished by simply punching slots in the proper holes on the edges of the card. For example, the name of the author is recorded along the bottom edge of the card, the alloy in question is recorded on the left-hand edge, and subjects of the reference (according to a previously established index, later to be described) are recorded by slotting the numbered holes along the top and right-hand edges. The cards are also large enough (5x8 in.) to hold on front and back rather extensive typed abstracts or printed clippings, affixed with thermoplastic cement.

Such cards need not be kept in any particular order, but instead are sorted using a needle that passes through the holes in the cards, Fig. 2. Cards that have had a particular hole removed by slotting are thus easily separated from the balance of the cards. Therefore, a file of punch cards, although in random order, can be said to be filed with respect to author, subject and alloy.

The operation of such a card file will now be described in some detail.

Hand-operated punch cards, the subject of this article, are available in a wide variety of sizes and hole designs.* In fact, a large number of the cards used for technical purposes are custom-designed. Now, the average metallurgist is primarily interested in finding answers to specific questions rather than in arranging his file in chronological or alphabetical order, as in published indexes. For this reason a new indexing system has been devised to yield specific information with a minimum of effort. A punch card having a double row of holes is used, as in Fig. 1. Two kinds of slots are made on such a card: a "deep" slot, which removes both holes, and a "shallow" slot, which removes only the outer hole.

The principle governing the use of the double-row card is that deep and shallow

Table I — Representative Method of Indexing, Using Punch Cards Having a Double Row of Holes

Material to Be Indexed	Holes to Be Punched		Punch Cards
	Deep	Shallow	
Steels			
Carbon	1	2	
Low-alloy	1	3	
High-alloy	1	4	
			Unpunched
Cast Irons			
Gray	2	1	
White	2	3	
Malleable	2	4	
			Punched for low-alloy steel
Copper-Base Alloys			
Brass	3	1	
Bronze	3	2	
Pseudo-bronzes	3	4	
			Punched for brass
Miscellaneous			
White metals	4	1	
Noble metals	4	2	
Others	4	3	

*Makers are listed at the end of this article.

slots can be sorted independently, provided they do not occur at the same pair. Its operation is illustrated by the simplified, hypothetical example of Table I, which shows how 12 materials might be indexed for filing by the use of four double holes.

After information had been recorded on cards punched according to this scheme, data on *low-alloy steel* could be obtained in the following manner: First a sorting would be made for all cards in the "steel" group by needling deep in position 1. The cards that fall are only those in the steel group, since the other cards are held on

The Punch Card File

The Author Index — In this index at the bottom of the card are located the first and second letters of the author's last name. The first letter is recorded by a deep punch in the appropriate section, and the second letter by a shallow punch. For example, in the reference shown in Fig. 1, "Barkow" is recorded by punching deep in B and shallow in A.

(In the event that the first and second letters of the author's last name are identical, as in

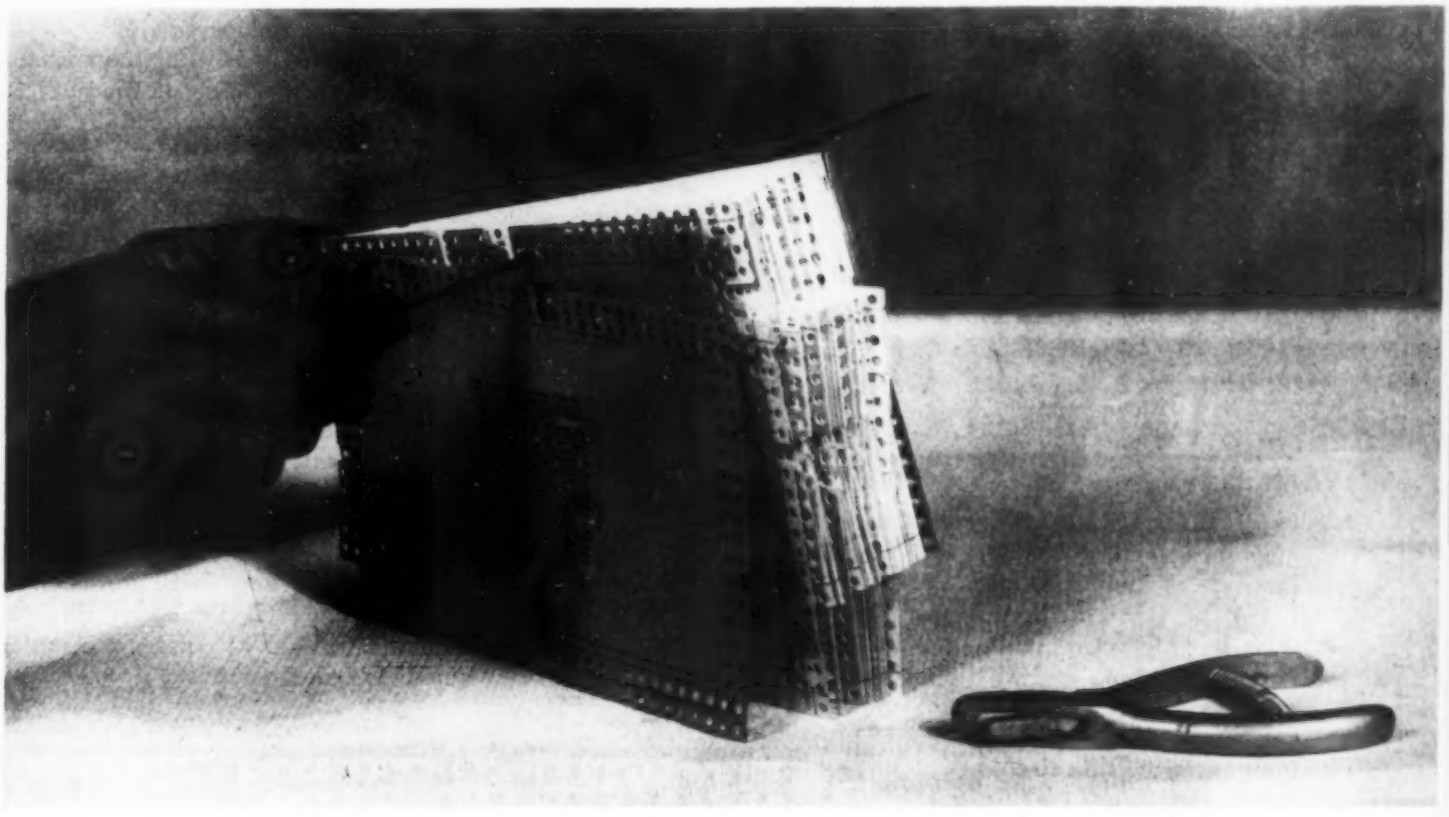


Fig. 2 — Sorting Punch Cards by a "Deep" Needling Operation. "Shallow" needling is done by passing the sorting needle through an outer hole

the needle by the presence of the inner hole in position 1. The cards that fall are then needled shallow in position 3. This time only cards referring to low-alloy steels fall from the pack.

It is significant that a card referring to brass, and hence punched deep in position 3, cannot fall in the second needling operation since it has been eliminated in the first operation; however, if a reference had included data on *both* low-alloy steel and brass, positions 1 and 3 both could be slotted deep and the card would drop when sorting for data on either material.

"Aaron", the deep punch is made in the appropriate hole, and the shallow punch is made in the hole following Z, marked D for "duplicate".)

If more than one man is author, the additional names can be recorded in the same manner as the first. Even though there is a possibility of obtaining cards not of the desired type if multiple authors are recorded, this is not a serious difficulty, since the "unwanted" cards are quickly rejected. Still, it is well to keep the number of authors recorded to a minimum. Usually there is little loss in usefulness of the file if only one or

Table II — Major Divisions of Subject Index

PROCESS METALLURGY
1. Mining, ores, beneficiation
2. Nonferrous reduction and refining
3. Ferrous reduction and refining

FORMING AND FABRICATION
4. Melting and casting
5. Metal working
6. Welding and joining
7. Powder metallurgy and miscellaneous forming processes
8. Cleaning, finishing, and surface treatment

TESTING AND INSPECTION
9. Analysis and inspection
10. Laboratory apparatus, instruments
11. Mechanical testing and properties
12. Physical testing and properties

PHYSICAL METALLURGY
13. Metallography and constitution diagrams
14. Heat treatment
15. Reactions in the solid and liquid states
16. X-rays, electrons, neutrons
17. Structure of metals and alloys
18. Deformation

CHEMICAL METALLURGY
19. Corrosion
20. Physical chemistry
    Thermodynamics
    Electrochemistry
    Miscellaneous

MISCELLANEOUS
21. Related subjects
22. Alloys classified by use and group

two authors are recorded out of three to five who may have written a given reference. This is in fact one of the advantages of the punch card — it can be elaborated by deeper and deeper subdivision at any time without disturbing the original classification, and with a minimum of trouble.

The Subject Index is the most important part of the filing system. Accordingly much time and effort were spent in attempting to make it as generally useful as possible. A tentative index was first set up and used for almost a year in order to determine its merit. On the basis of this experience a revised index was made and distributed to a number of qualified metallurgists for criticism. The suggestions received from them were incorporated in the final version given on pages 998 and 999.

The philosophy underlying it is that it should not be so narrow as to restrict the field; rather it should facilitate the filing of information covering a wide range of topics. Further, there should be ample space for extending the index in any possible direction. In order to attain the desired breadth of coverage it was sometimes necessary to sacrifice the detail necessary to a specialist in a given field. However, he should have no difficulty in suitably extending the index to meet his needs.

The section of the card used for the subject index is located along the top and right-hand edges and consists of 46 numbered double-holes plus the holes marked T, A, and G at the bottom. The 22 numbered *major divisions* of the subject index shown in Table II are recorded by *deep punches* at the corresponding positions along the top of the card. The minor divisions listed under each major division on page 998 are recorded by *shallow punches* in the corresponding locations on the top and right edge. Thus, to indicate that a reference deals with "forging", for example, a deep punch is made at position 5 (metal working), and a shallow punch at position 28 (forging).

Figure 1 shows how two different subjects can be indexed on a single card. "Fatigue" is listed under "mechanical testing and properties" and is to be recorded by a deep punch in 11 and a shallow punch in 15. Since X-ray diffraction is an important subject of this reference, it also has been recorded by punching deep in 16 and shallow in 30, which corresponds to the minor division "X-ray methods and equipment" under the major division "X-rays, electrons, neutrons". Recording

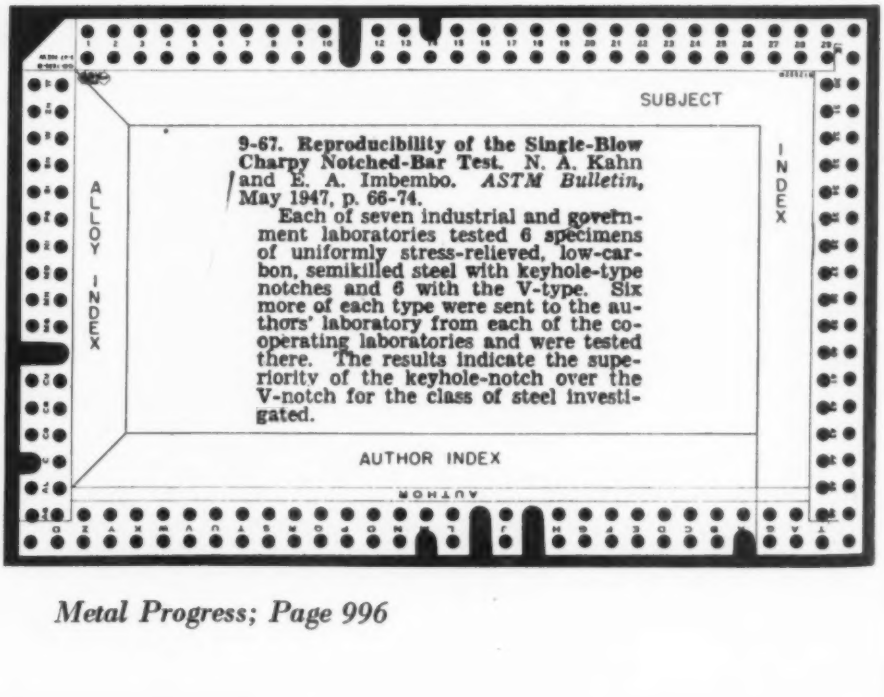

SUBJECT
9-67. Reproducibility of the Single-Blow Charpy Notched-Bar Test. N. A. Kahn and E. A. Imbembo. ASTM Bulletin, May 1947, p. 66-74.
Each of seven industrial and government laboratories tested 6 specimens of uniformly stress-relieved, low-carbon, semikilled steel with keyhole-type notches and 6 with the V-type. Six more of each type were sent to the authors' laboratory from each of the cooperating laboratories and were tested there. The results indicate the superiority of the keyhole-notch over the V-notch for the class of steel investigated.
INDEX
ALLOY INDEX
AUTHOR INDEX

Fig. 3 — Indexed Punch Card (Abstract From Metals Review *Cemented on) Punched for Division (11), Subject (14), Two Authors, and Carbon Steel*

more than one item, such as fatigue, in the subject index introduces the possibility of obtaining unwanted cards when needling, but the staggered numbering of the minor divisions in the subject index reduces this possibility to such an extent that one can record two or three items per reference with little chance of extra work when sorting.

In addition to the minor divisions listed in the subject index, page 998, each major division can have "theory", "application", or "general" listed under it by a suitable shallow punch in the respective location marked T, A, or G on the lower edge of the punch card.

The capacity of the subject index is 46 major divisions, each having 45 minor divisions. Since only 22 major divisions are employed in our classification and only 10 or so of the minor divisions, there is provision for eight-fold expansion of the subject index by the individual user of the file! This *growth* feature is insurance that the index will not be bursting at the welds after a few years of use.

Most practicing engineers build up a personalized collection of data, references, and miscellaneous information that quickly becomes too bulky and complex for use by anyone except him who keeps it in order. Even then the scheme always fails to locate available information on minor Subject A when it has been indexed or placed under major Subject B. The punch card with a needle for a sorting instrument is a beautifully simple way of getting in jig time all references in a card file applying to a certain subject, a certain metal or alloy, or written by a certain author. The cards, also, can be scrambled — all that is necessary is that they be right side up, facing front.

The Alloy Index, given on page 999, consists of two parts — the elements listed directly on the left-hand side of the punch card, and elements given by code number. It is likely that 90% of the references can be indexed directly. An example is shown in Fig. 1; the material cited in this reference is aluminum containing copper as the major addition. The major element is indexed by punching deep in the proper position — Al, in this case. Copper is indicated as being a minor element by making a shallow punch in the Cu position. If it were desirable to record that the influence of silicon, manganese, and magnesium present in 14S-T alloy were discussed in this article of Barkow's, this could be done by additional shallow punches.

The less common elements or groups of elements are listed by code numbers, which refer to shallow positions in the subject index portion of the card. The π location at top left corner is used in conjunction with elements spotted by code number. Just as a deep punch in one of the sections of the alloy index signifies that the indicated *directly listed* element (like Al, Fe, or Si) is the major constituent of the metal of the given reference, so a deep punch in the π section signifies that one of the *coded* elements is the major constituent. For example, a reference on indium-base alloys is indexed by punching deep in π and shallow in 17. To show that a coded element is a *minor* constituent, it is only necessary to punch shallow in π.

The single hole E at the upper right corner of the card is also used in the alloy index. Punching this section indicates that the reference deals with the unalloyed element. If this section were not used it would be difficult to separate such references from those dealing with the more common alloyed elements.

While objection can be made to the dual use of positions in the subject index, it appears that the advantages of this arrangement of indexing the less common metals far outweigh the disadvantages. Only a small percentage of references will need this dual use, and unwanted cards obtained as a result will be very few. On the other hand, the advantage of being able to index every element rather precisely is considerable.

Preparation of Cards

Because the preceding discussion of the use of the punch card indexes was necessarily rather detailed, it is probably worth while to give the bare requirements for indexing a given reference:

1. With the cut off corner of the punch card to the upper left, **record the usual information** on the body of the card. If the reference has been abstracted in *Metals Review* or another journal, it is convenient to clip the abstract and simply cement it on punch card (Fig. 3).

(Conclusion of the text of this article is on page 1000, after the indexes)

Subject Index for Metallurgical Filing System

Process Metallurgy

1. Mining, Ores, Beneficiation
2. Geology
3. Mineralogy
4. Mining
5. Ores
6. Milling and crushing (sizing)
7. Classification
8. Heavy fluid separation
9. Flotation
10. Magnetic separation

2. Nonferrous Reduction and Refining

5. Flow sheets
6. Roasting
7. Sintering
8. Smelting
9. Converting
10. Distillation
11. Leaching
12. Fire refining
13. Electrometallurgy
14. Chemical refining
15. Casting
16. Slag, dross, slime treatment
17. Precious metal recovery
18. Secondary metals

3. Ferrous Reduction and Refining

10. Blast furnace
11. Bessemer
12. Basic openhearth
13. Acid openhearth
14. Duplex process
15. Electric furnace
16. Crucible process
17. Wrought iron
18. Direct reduction
19. Molds and pouring

Forming and Fabrication

4. Melting and Casting

15. Melting furnaces and techniques
16. Patterns, molds and molding
17. Sand castings
18. Precision castings
19. Permanent mold castings
20. Die casting
21. Centrifugal casting
22. Plaster casting
23. Continuous casting
24. Ingot casting
25. Casting defects (also 9-44, 45, 46, 1)

5. Metal Working

20. Ingot treatment
21. Rolling
22. Extrusion
23. Tube making
24. Wire drawing
25. Deep drawing
26. Straightening
27. Spinning
28. Forging
29. Swaging
30. Stamping, coining, punching
31. Bending
32. Pressing
33. Machining
34. Grinding
35. Shearing

6. Welding and Joining

25. Weldability
26. Gas welding
27. Arc welding
28. Resistance welding
29. Flame cutting
30. Soldering
31. Brazing

7. Powder Metallurgy and Miscellaneous Forming Processes

30. Metal powders
31. Pressing
32. Sintering
33. .....
40. Electroforming
    Metal spraying (8-44)
41. .....

8. Cleaning, Finishing and Surface Treatment

35. Mechanical cleaning and polishing
36. Chemical and electrochemical cleaning
37. Paint, wax, other nonmetallic coats
38. Enameling
39. Dip coating
40. Diffusion coatings
41. Chemical coatings
42. Anodizing
43. Coloring
44. Metal spraying
45. Casehardening
46. Electroplating
1. Electropolishing

Testing and Inspection

9. Analysis and Inspection

40. Wet methods
41. Spot tests
42. Assaying
43. Spectrographic testing
44. Magnetic particle testing
45. Supersonic testing
46. Fluorescent dye testing
    X-ray equipment (16-30)
1. Radiographic inspection
2. Gas analysis
    Electrical testing (12-10)
3. Surface finish measurements

10. Laboratory Apparatus, Instruments

1. Furnaces
2. Vacuum techniques
3. Temperature measurement and control

11. Mechanical Testing and Properties

5. Low temperature
6. High temperature
7. Tensile
8. Rupture
9. Creep
10. Compression
12. Torsion
13. Bend
14. Impact and high speed
15. Fatigue
16. Damping
17. Wear
18. Machinability
19. Hardness

12. Physical Testing and Properties

10. Electrical properties
11. Thermoelectric properties
13. Magnetic (also 15-35)
14. Optical properties
15. Density
16. Thermal expansion
17. Thermal conductivity
18. Specific heats
19. Changes of state (temperatures and latent heats)
20. Friction

Physical Metallurgy

13. Metallography and Constitution Diagrams

15. Specimen preparation
16. Etching
17. Photography
18. Macrography
19. Photomicrography
20. Interpretation of photomicrographs
21. Microradiography
    X-ray equipment (16-30)
    Electron microscopy (16-31)
22. Thermal analysis
23. Binary constitution diagrams
24. Ternary constitution diagrams

14. Heat Treatment

20. Furnaces
21. Salt and lead baths
22. Induction heating
23. Flame hardening
    Casehardening (8-45)
24. Heat flow
25. Controlled atmospheres
26. Hardening
27. Annealing
28. Tempering
29. Solution treatment
30. Precipitation (also 15-30)
31. Quenching
32. Distortion and cracking
33. Hardenability (also 15-29)
34. Jominy curves
35. Isothermal treatments
36. TTT or S-curves
37. Subzero treatments

15. Reactions in the Solid and Liquid States

25. Diffusion
26. Recovery
27. Recrystallization (also 17-39)
28. Nucleation and growth of grains
29. Eutectoid reaction (also 14-33)
30. Precipitation (also 14-30)
31. Superlattice formation
32. Allotropic transformation
33. Liquid-solid transformation
34. Vapor-solid, vapor-liquid transformation
35. Magnetic transition (also 12-13)

16. X-Rays, Electrons, Neutrons

30. X-ray methods and equipment
31. Electron microscopy
32. Electron diffraction
33. Neutron diffraction
34. Tracer technique

17. Structure of Metals and Alloys

35. Nuclear structure
36. Atomic structure
37. Crystallography and crystal structure
38. Intermediate phases and metallic compounds
    Superlattices (15-31)
39. Preferred orientation (also 15-27)
40. Grain structure and size
41. Crystal imperfections
42. Liquid metals
43. Solid solutions
44. Segregation

18. Deformation

40. Elasticity
41. Plasticity
42. Slip
43. Twinning
44. Deformation of single crystals
45. Effect on structure (also 17-39)
46. Effect on properties
1. Anelasticity
2. Stress and strain measurements
3. Complex stresses
4. Residual stresses
5. Strain hardening
6. Fracture

Chemical Metallurgy

19. Corrosion

1. In liquids
2. In gases
3. Atmospheric
4. High temperature
5. Protection
6. Laboratory testing methods
7. Stress-corrosion cracking
8. Passivity
9. Fretting corrosion

20. Physical Chemistry

Thermodynamics:
5. General
6. Theory
   Specific heats (12-18)
7. Entropy
8. Free energy
9. Phase changes (also 12-19)
10. Metallurgical reactions

Electrochemistry:
21. General
22. Theory
23. Solution potential

Miscellaneous:
30. Gases in metals
31. Surface chemistry

Miscellaneous

21. Related Subjects

10. Organic chemistry
11. Inorganic chemistry
12. Mathematics
13. Physics — heat
14. light
15. sound
16. mechanics
17. electricity and magnetism
18. Foreign languages
19. Statistics — general
20. statistical analysis
22. metal economics
23. Writing manuals
24. Teaching methods
25. History of metallurgy
26. Electronics
27. Specifications
28. Refractories

22. Alloys Classified by Use and Group

15. Cast
16. Wrought
17. Bearing
18. High temperature
19. Low temperature
20. Corrosion resisting
21. Magnetic — soft
23. Magnetic — permanent
24. Electrical resistance
25. Cutting
26. Wear resisting
27. Structural
28. Automotive

Alloy Classification

Elements Listed Directly

Ag — Silver
Al — Aluminum
C — Carbon
Co — Cobalt
Cr — Chromium
Cu — Copper
Fe — Iron
Mg — Magnesium
Mn — Manganese
Mo — Molybdenum
Ni — Nickel
Pb — Lead
Si — Silicon
Sn — Tin
W — Tungsten
Zn — Zinc

Elements Given by Code Number

1. Actinium
2. Antimony
3. Arsenic
4. Barium
5. Beryllium
6. Bismuth
7. Boron
8. Cadmium
9. Calcium
10. Columbium
11. Francium
12. Gallium
13. Germanium
14. Gold
15. Hafnium
16. Hydrogen
17. Indium
18. Masurium
19. Mercury
20. Nitrogen
21. Oxygen
22. Phosphorus
23. Polonium
24. Protoactinium
25. Radium
26. Rhenium
27. Scandium
28. Selenium
29. Strontium
30. Sulphur
31. Tantalum
32. Tellurium
33. Thallium
34. Thorium
35. Titanium
36. Uranium
37. Vanadium
38. Yttrium
39. Zirconium
40. Platinum-Palladium groups
    Iridium
    Osmium
    Palladium
    Platinum
    Rhodium
    Ruthenium
41. Alkali group
    Caesium
    Lithium
    Potassium
    Rubidium
    Sodium
42. Halogens
    Alabamine
    Bromine
    Chlorine
    Fluorine
    Iodine
43. Rare gases
    Argon
    Helium
    Krypton
    Neon, Radon, Xenon
44. Rare earth group
    Cerium
    Dysprosium
    Erbium, Europium
    Gadolinium
    Holmium, Illinium
    Lanthanum
    Lutecium
    Neodymium
    Prasodymium
    Samarium, Terbium
    Thulium, Ytterbium
45. Trans-Uranium group
    Americium, Curium
    Neptunium
    Plutonium

2. **Index the author's name** by

(a) Deep punching the first letter of his last name,

(b) Shallow punching the second letter of his last name. Preferably not more than two names should be indexed for a given reference.

3. **Index the subjects** of the reference by

(a) Deep punching the corresponding major division from Table II,

(b) Shallow punching the proper minor division from the subject index, pages 998 and 999.

Do this for each subject of interest contained in the reference.

4. **Index the alloy** of the reference by

(a) Deep punching the section of the alloy index corresponding to the major constituent; if the major element is not listed directly a deep punch should be made in position π and a shallow punch in the proper numbered position as determined from the alloy classification, page 999;

(b) Shallow punching the position or positions of the alloy index corresponding to the minor elements. If the minor element is not listed directly a shallow punch should be made in position π and a shallow punch in the proper code numbered position.

Filing and Storage

An important point is that the cards are stored *in random order* in an ordinary 5x8-in. file drawer. A punch card anywhere in the file is in perfect order! When the cards are to be sorted by a needling operation, they are handled in groups of about 100. A file of 1000 cards can be sorted for all the cards by a given author or for all the cards on a given subject in not more than a minute or two.

The dog-eared corner determines that none of the cards is upside down. If the cards are mixed, needling through the upper left corner of the pack will permit those which are topside up and face up to drop. In three needling operations all cards can be made right side up, which is obviously necessary before using the file.

When one has collected a few hundred punch card references, how are they used to obtain useful information? First the code numbers must be determined. To aid in quickly locating items in the subject and alloy indexes, the classifications on pages 998 and 999 may be posted for ready reference near the file.

Another scheme is to post Table II and then make 22 5x8-in. cards with numeral tabs on top for the 22 major subdivisions. These can be placed in the front of the first file drawer. When the cards are to be searched for a given subject, a glance at the table shows the number of the proper major division. The corresponding 5x8-in. card is consulted for the number of the proper minor division. Deep and shallow needling operations then locate the desired cards.

For example, suppose one wishes to find cards giving information on the creep strength of cartridge brass (70% copper, 30% zinc). Sorting would be done with respect to the alloy index first, since irrelevant cards would be more quickly eliminated. Deep needling the Cu section of the alloy index would separate cards referring to copper-base alloys. These cards would be needled shallow in the Zn section to select only cards referring to the brasses or other alloys containing both copper and zinc.

If the number of cards yielded by this procedure were too great to be searched for the desired information on creep strength, an additional sorting could be performed, using the subject index. The proper major division from the subject index is 11, Mechanical Testing and Properties, and "creep" is minor division 9. Therefore sorting would be done by deep needling in 11 and shallow needling in 9. The cards selected by this dual sorting, with respect to alloy and with respect to subject, would refer to information on the creep of copper-base alloys containing zinc.

The equipment necessary to set up this system is simple and inexpensive. In addition to the standard file cabinets the only requirements are suitable punch cards, a slotting punch, and a sorting needle. These are shown in Fig. 2. The cost of both punch and sorting needle is about $3.00, while the cards cost 1 to 2¢ each, depending on the type and quantity ordered. Keysort Cards can be obtained from the McBee Co., Athens, Ohio; Pathfinder cards from the Charles R. Hadley Co., 330 North Los Angeles St., Los Angeles, Calif.; and E-Z Sort cards from the L. M. Osbourne Co., 45 Second St., San Francisco 5, Calif., or Business Control Service, 32 Oliver St., Boston 17, Mass.

Supplementary Uses

Although this article has described only the application of punch cards to the filing of metallurgical literature, there are many other uses for these cards in the industry. For example, when a variety of tests is to be made on a series of materials, it is a simple matter to arrange a suitable indexing system that will allow the results to be conveniently recorded on punch cards, ready for sorting in any desired combination. A number of such applications have been made in General Electric's research laboratory.

PEOPLE DON'T STANDARDIZE ON "SUBSTITUTES"

For nearly 15 years, molybdenum high speed steels have *proved on their own merits* that they are *superior* steels. Long before World War II, during the war, and up to the present moment, these steels have done *more* work for *less* money.

Molybdenum high speed tool steels, for instance, are not only tougher, and do more work per job, but are consistently cheaper than 18-4-1. In addition, they are from 6% to 9% less dense, so more tools may be made from the same gross weight of steel.*

Get the facts about what molybdenum high speed steels can do for you.

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MOLY

Personals

James J. McCarthy has recently joined the metallurgical department of the Johnstown, Pa., plant of the Bethlehem Steel Co.

R. W. Heine, formerly instructor in the science department at General Motors Institute, has accepted a position as instructor in the department of mining and metallurgy, University of Wisconsin, Madison, Wis., teaching courses in foundry metallurgy and metallography.

Paul L. Chester is now employed at the Pittsburg, Calif., works of the Columbia Steel Co. as metallurgist in the openhearth and rolling mill division.

Western Electric Co. has transferred **W. G. Leaman** from the Kearny, N. J., to the Buffalo, N. Y., works, where he will be materials engineer.

Eugene H. Kinelski, formerly at the applied physics laboratory of Johns Hopkins University, is now metallurgical engineer at the Cornell Aeronautical Lab. in Buffalo, N. Y.

R. J. Nadherny is now associated with Barnes & Reinecke, Inc., engineers and contractors, as chief engineer.

After graduating from Sibley School of Mechanical Engineering, Cornell University, **Joseph E. Nemeth** joined the glass division of the Pittsburgh Plate Glass Co. in their Ford City, Pa., plant as an engineer in their training program.

Carl A. Julien, formerly graduate student and staff member at the University of Notre Dame, is employed as a metallurgist at the U. S. Naval Research Lab., Anacostia, D. C.

Previously at General Electric Co., Schenectady, N. Y., **A. G. Guy** is now head of the metallurgy section in the mechanical engineering department of North Carolina State College.

B. Sadasiva Raju is enrolled at McGill University for a postgraduate course in mineral dressing.

Robert S. Gregg, formerly chief metallurgist of Ingersoll Steel Division of the Borg-Warner Corp., is now associated with the John Bean Division, Food Machinery Corp., Lansing, Mich., as director of the laboratory and in charge of quality control of the Belding foundry division of the corporation.

On graduation from Cornell University this past June, **Eugene S. Carlson** joined the Worthington Pump Corp., Harrison, N. J., as student engineer.

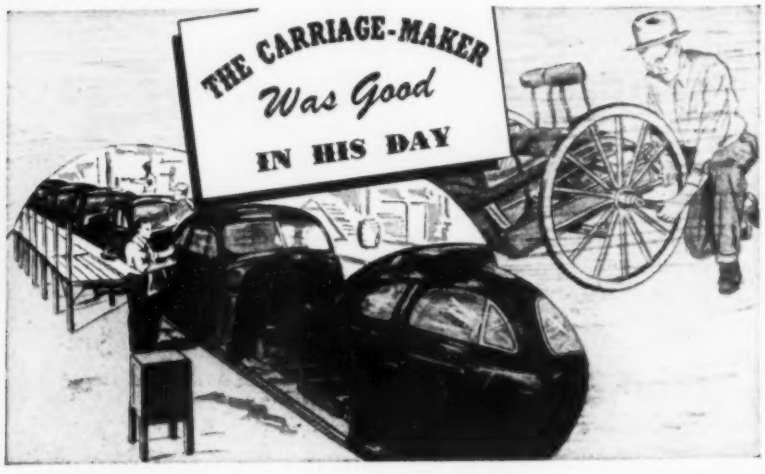
O. H. Kuhlke is now with General American Transportation Corp. as technical instructor.

Herbert B. Robinson has been appointed assistant to the director of the service and development laboratories of the A. O. Smith Corp., Los Angeles, Calif.

V. J. Gauthier has been appointed assistant professor in the mechanical engineering department at New York University, where he will be in charge of the machine tool laboratory and the metal cutting research.

Walton R. Yerger, formerly with the Sikorsky Div., United Aircraft Corp., is now metallurgical engineer for American Screw Co., Providence, R. I.

James H. Hinman has been appointed assistant technical adviser and transferred from the Rome division to the New Bedford division of Revere Copper and Brass, Inc.



BUT . . .

His plodding—time-consuming—methods would be as hopelessly outdated as old fashioned ways of cleaning metals.

Duridine*

used in power spray washers of mild steel, provides modern metal cleaning and phosphate-coating that is rapid—effective—economical. It removes oil, grease and other foreign surface matter—phosphatizes—changes the surface to a non-conductive phosphate film of uniform crystalline consistency. "DURIDINE" establishes a lasting adhesive bond for paint finishes. In addition, this bond prevents rust encroachment when painted surfaces are accidentally scratched or dented.

For proper cleaning and effective phosphatizing of metal surfaces—specify "DURIDINE".

*® for Metal Cleaning and Coating Chemicals

CHEMICALS ACP PROCESSES

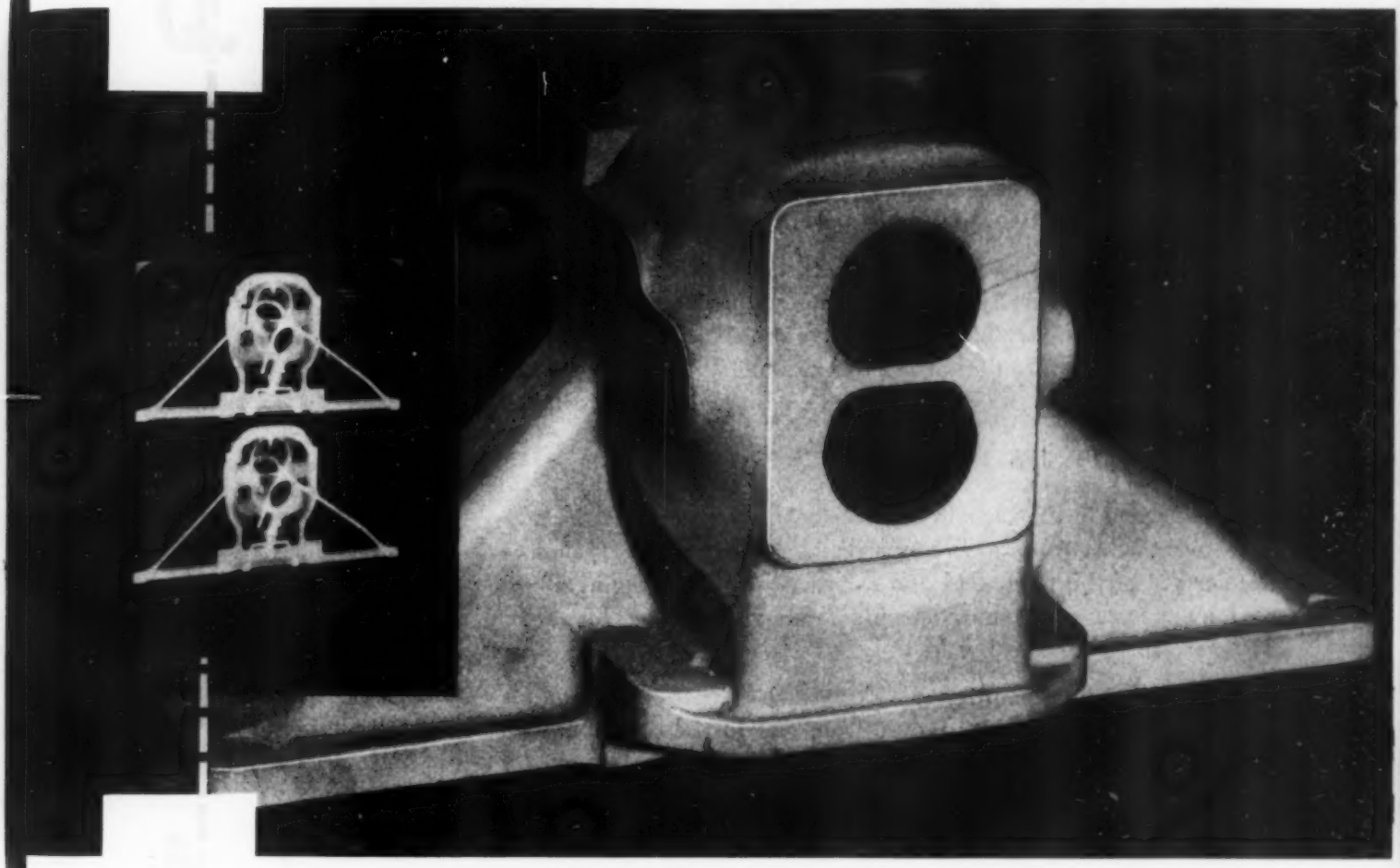
RUST PROOFING AND PAINT BONDING
Granodine *
Duridine *
Alodine *
Lithoform *
Thermoil-Granodine *

RUST REMOVING AND PREVENTING
Deoxidine *
Peroline *

PICKLING ACID INHIBITORS
Rodine * ®

AMERICAN CHEMICAL PAINT CO.
AMBLER ACP PENNA.

Which x-ray film is the first choice for routine 100 kv. radiography of this magnesium casting?



Kodak's Type A

LIGHT metal castings from this foundry have the reputation for being high-grade . . . because they're radiographed before release.

This radiograph shows just what the customer gets—a casting free of voids, gas holes, porosity, and shrinkage weaknesses, which might otherwise prove costly later on. Kodak Industrial X-ray Film, Type A, was used for the picture.

Why Type A? . . . Because it is well adapted to the short exposure times required by production scheduling. Because it provides the high radiographic sensitivity—extremely high contrast and fine grain—necessary for greatest detail visibility in the critical radiographic inspection of magnesium, aluminum, and their alloys.

Radiography often more than pays for itself. In the foundry, savings not only exceed the cost of x-ray equipment and operations by reductions in customer rejections, but, by nondestructive testing, radiography points the way to more exact casting methods. On the production line, it saves by showing internal defects before expensive machining gets underway—avoiding broken tools, wasted machine time, and delays in production.

EASTMAN KODAK COMPANY
X-ray Division, Rochester 4, N. Y

Other Kodak Industrial X-ray Films

Kodak Industrial X-ray Film, Type F . . . with calcium tungstate screens—primarily for radiography of heavy steel parts. The fastest possible radiographic procedure.

Type M . . . first choice in critical inspection of light alloys or in the examination of thin steel at moderate voltages and heavy alloy parts with million-volt equipment.

Kodak Industrial X-ray Film, Type K . . . primarily for gamma- and x-ray radiography of heavy steel parts, or of lighter parts at limited voltages where high film speed is needed.

Radiography

. . . another important function of photography

Kodak

Strengthens Plug Welds with "Fleetweld 47"

ONE of the problems encountered by Berg Manufacturing & Sales Co., Chicago, in making its "Shur-Lift" auto jack, was the joining of channels to top and bottom non-skid plates in such a way that they would not break apart under varying stresses. It was decided that a center connection, with plug welds, would be most reliable.

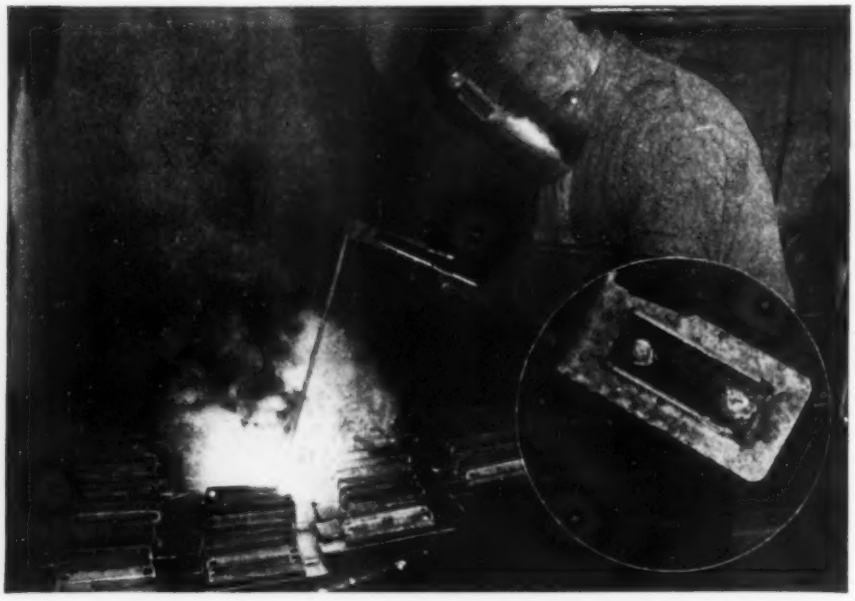
Berg had difficulty making plug welds that would withstand the toughest service, especially the tension caused when a car axle slips off-center on the top plate. The slag of conventional E-6010 electrodes did not always wash to the surface during welding, resulting in slag inclusions which kept the weld from developing maximum strength.

TESTS PROVED STRENGTH

They called in the Lincoln engineer, who recommended the new "Fleetweld 47" electrode. It has a very light slag which washes to the surface of the plug weld and is practically self-cleaning. Berg conducted tests and found the plug welds made with "Fleetweld 47" were impossible to break.

In production, a quantity of tack-welded assemblies are laid out on a table, and the welder moves from one to the other without raising his helmet. Photo shows this operation and a completed weld. A 7/32" electrode is used with current at 300 amps.

To make plug welds, welder moves from one assembly to another without raising shield. Inset: completed plug welds.



The above is published by LINCOLN ELECTRIC in the interests of progress. Properties and procedures of "Fleetweld 47" are given in Bul. 403, The Welding Guide. Write The Lincoln Electric Company, Dept. 234, Cleveland 1, O.

Personals

Rudolf W. Zillmann is enrolled at Massachusetts Institute of Technology where he is working toward his Sc.D. degree.

Formerly with Addressograph-Multigraph Corp., **Claude Landusky** has become associated with the Perfection Stove Co., Cleveland, as metallurgist.

Having severed his connections with CBS Steel & Forge Co., **Alexander Zekany** has joined Peck Steel & Die Supply, Los Angeles, as metallurgical sales engineer.

Albert Craig Levinson is now employed by American Smelting & Refining Co. as metallurgical engineer in the Omaha lead refinery.

R. A. Galuzevski is now on the staff of the University of California as instructor in mechanical engineering, teaching courses in tool engineering and conducting research in metal cutting.

John R. Lewis, formerly development engineer for Titanium Alloy Mfg. Co., is now president and manager of the newly formed Lewis Casting Co., Inc., Lewiston, N. Y., producers of nonferrous castings.

Federated Metals announces the promotion of **A. S. Wigle**, former plant superintendent at the Whiting, Ind., plant to superintendent of all Whiting operations.

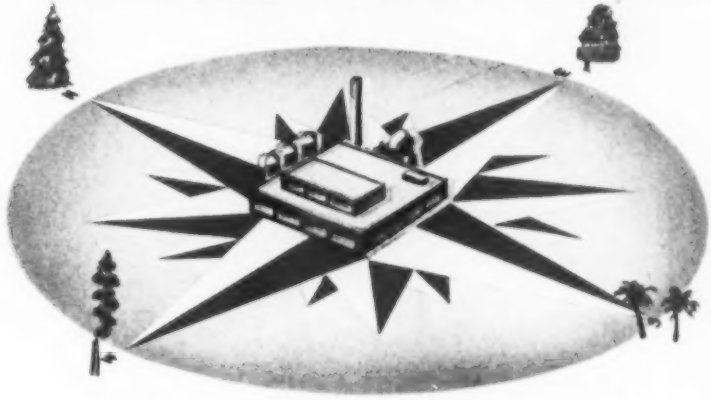
Jerome G. Brady has been appointed by Kennametal, Inc., Latrobe, Pa., as tool engineer and representative in the Pittsburgh district office.

The first holder of the new professorship of metallurgical engineering at Cornell University, endowed by F. N. Bard of Barco Mfg. Co., Chicago, is **Peter E. Kyle**. Before coming to the Cornell faculty last year, Professor Kyle taught materials and metals processing for 12 years at Massachusetts Institute of Technology. The newly established School of Chemical & Metallurgical Engineering will offer a 5-yr. course of study leading to the degree of Bachelor of Engineering with majors in either metallurgical or chemical engineering.

Babcock & Wilcox Tube Company has appointed **Frederick H. Foglesong**, formerly with the Steel & Tube Division of the Timken Roller Bearing Co., to the staff of their Detroit district sales office.

OUR PLANTS BLOOM THE YEAR 'ROUND

...IN YOUR BACK YARD!



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BAY POINT WORKS
San Francisco (Port Chicago), Calif.
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Johnsonburg, Pa.
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Kalamazoo, Mich.
MENASHA WORKS*
Menasha, Wisc.
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Middletown, Ohio
MONROE WORKS
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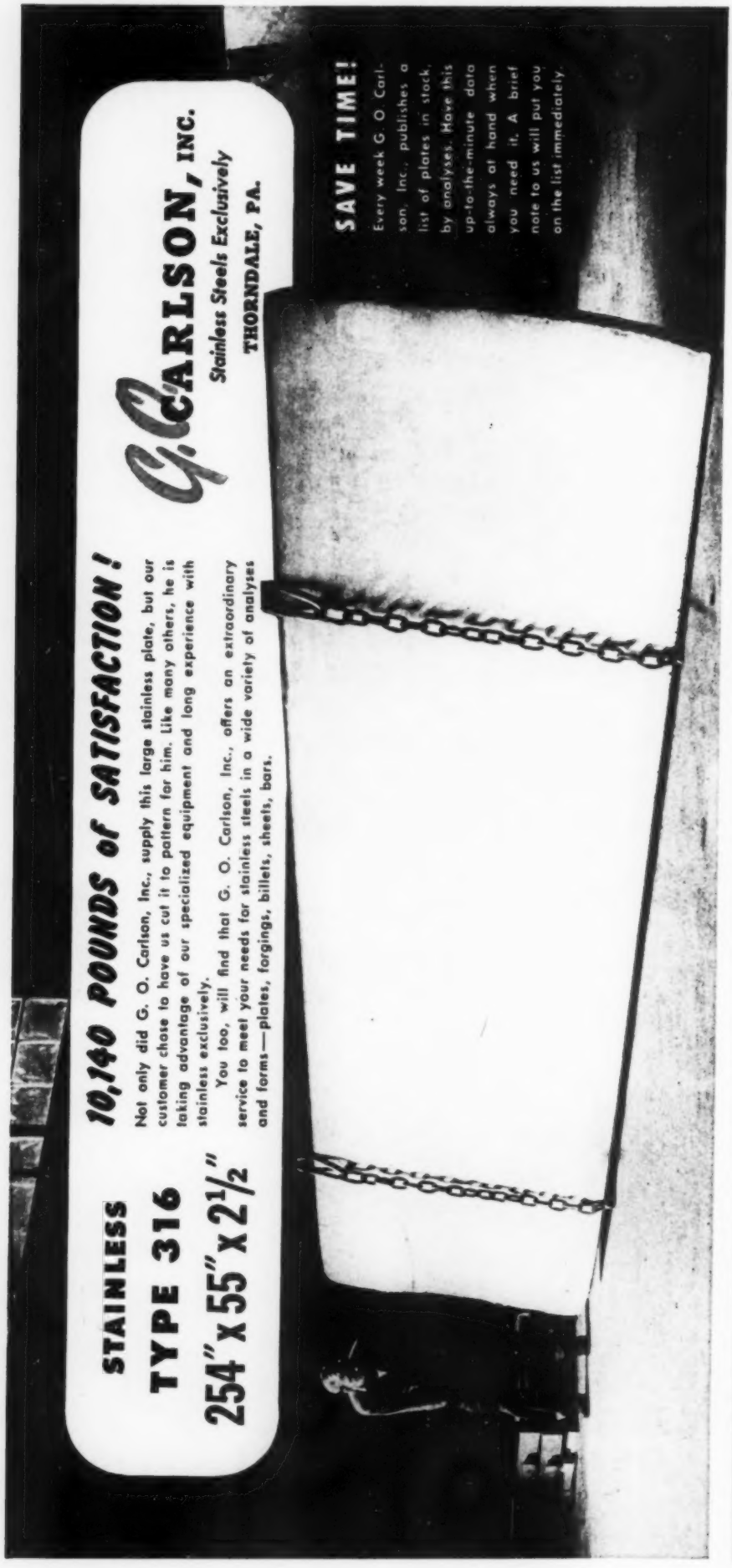
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Personals

Johan Bjorksten, president of Bjorksten Research Laboratories, Chicago, has been elected a director of the Association of Consulting Chemists and Chemical Engineers, Inc.

Battelle Memorial Institute announces the appointment of **Vincent D. Barth** to its staff. A former chemical engineer with the U. S. Bureau of Reclamation, he will conduct research in nonferrous metallurgy.

Irving L. Herts, chairman of the Pueblo Group, Rocky Mountain Chapter, A.S.M., was appointed superintendent of the newly created production planning and shipping department of the Colorado Fuel and Iron Corp. He was previously assistant to the superintendent of the order and shipping dept. **Hal Sorenson** was appointed assistant superintendent of the production planning and shipping department, and C. J. **Vidmar**, secretary-treasurer of the Pueblo Group, was made general foreman of the wire mill scheduling, shipping and stockkeeping section, succeeding Mr. Sorenson.

L. W. Cashdollar, until recently chief metallurgist for the Hinderliter Tool Co., is now with the Union Electric Steel Corp., of Carnegie, Pa.

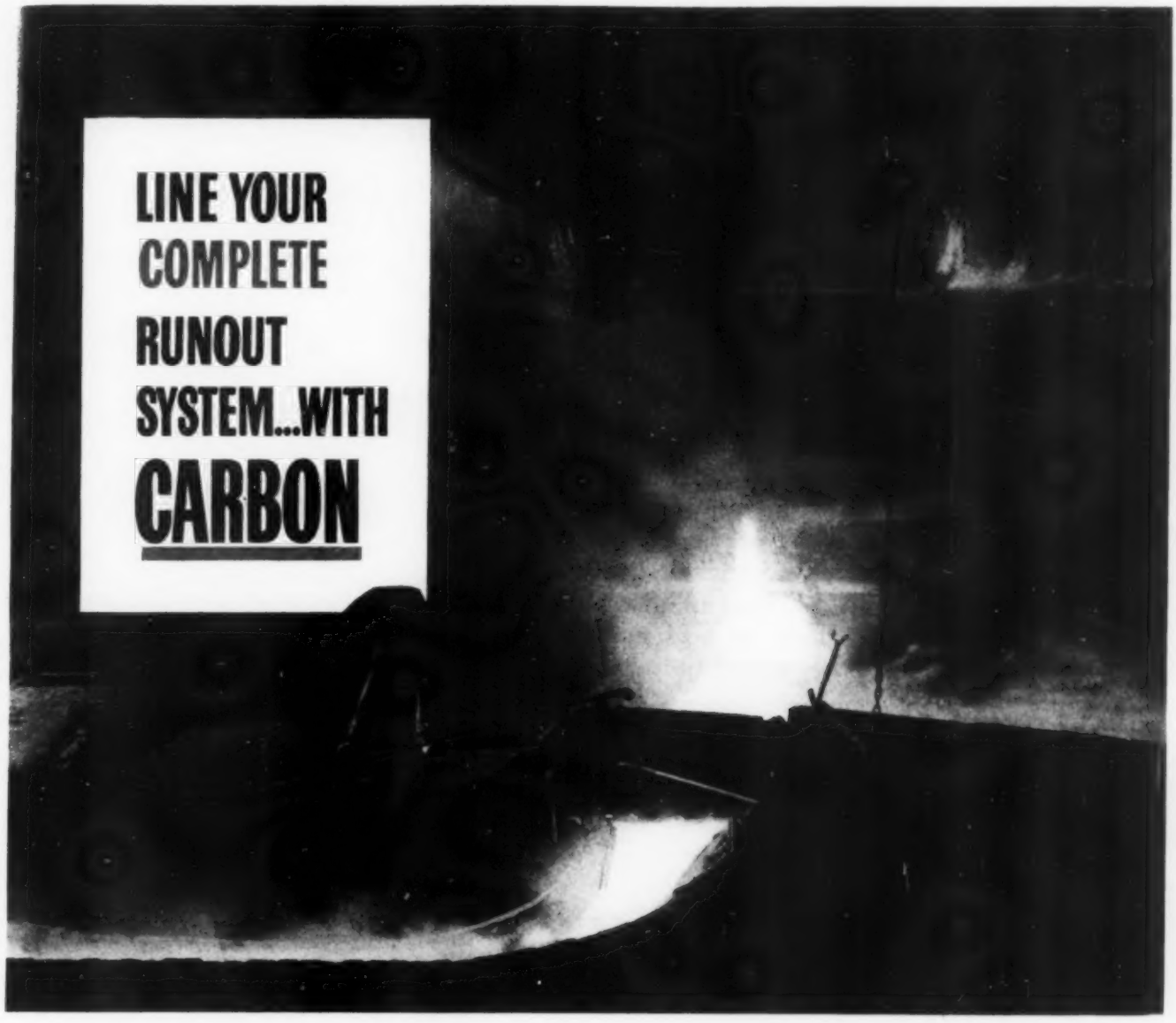
W. F. McGarrity has been named manager of sales promotion and development of Weirton Steel Co. He was previously assistant manager of the department.

Gray Iron Research Institute has named **Daniel E. Krause** as its executive director. Mr. Krause has been associated with Gray Iron Research Institute activities as a member of the Battelle Memorial Institute staff.

Claus G. Goetzel, formerly technical director of American Electro Metal Corp. and still director of powder metallurgy courses at New York University, has been instrumental in the organization of Sintercast Corp. of America, New York, of which he is vice-president and director of research.

G. H. McCalley has been promoted from superintendent of the melting department to plant superintendent of Burlington Steel Co., Ltd., Hamilton, Ont.

Robert L. Klein, former director of research of Presmet Corp., has assumed the presidency of the Windalume Corp., West New York, N. J.



● "National" carbon-block linings have for years been doing a fine job in blast furnace runout troughs —between taphole and skimmer plate.

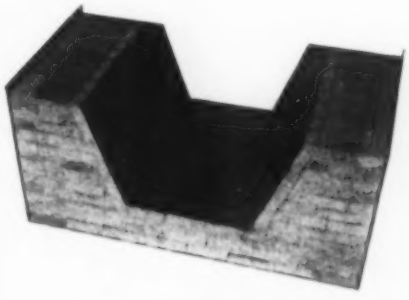
Why stop there?

Why not use carbon linings for the entire system, from furnace to ladle, and in the lead-in spouts of the pig machine as well? Carbon-block construction, shown at right, is recommended to the skimmer plate. Carbon bricks are most practical for the rest of the troughs.

Why use carbon?

Carbon outlasts other trough linings by months, even years. It is unaffected by thermal shock. Hot metal will not stick to carbon; so, if any skull is formed in the trough, it is readily removed. Furthermore, if you desulphurize in the trough, you'll find that carbon is highly resistant to desulphurizing agents.

Here is the recommended construction for a carbon-block trough between taphole and skimmer plate. Dark section is carbon. Light section is firebrick.



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Manganese copper is used principally for the introduction of Manganese into brass, bronze and nickel silver. It is supplied in the form of shot or bars that can be cut to any reasonable weight that the user may require.

GRADE "A"—

will conform to the following composition:

Manganese	28.5 to 31.5%
Total Impurities	0.5% Maximum
Copper	Balance

GRADE "B"—

will conform to the following composition:

Manganese	25.0 to 30.0%
Total Impurities (Principally Iron)	3.0 to 5.0%
Copper	Balance

"FALLS" MANGANESE COPPER is also used for deoxidizing brass, white nickel casting alloys and nickel silver containing lead. As well as being an active deoxidizing agent Manganese has great affinity for sulphur and this combined with its ability to absorb gases makes "FALLS" MANGANESE COPPER a very important alloy for use in the foundry.

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Smelting & Refining Division

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Personals

H. C. Barber has been appointed instructor in mechanical engineering at the University of Texas, where he will assist in developing a department of metallurgy.

Following completion of his studies for a M.S. degree in metallurgical engineering at Carnegie Institute of Technology, **William C. Banks** has recently become assistant to the chief metallurgist, Fort Pitt Steel Casting Div., Pittsburgh Steel Foundry Corp., McKeesport, Pa.

Warren Adkins is now employed at instrument making for the physical science laboratory at the New Mexico College, Los Cruces, N. M.

Charles Hardy, Inc., announces the addition of **Herman Mansfield** as metallurgist on the laboratory staff. Mr. Mansfield is a recent graduate of the Missouri School of Mines.

George Stern, formerly chief metallurgist, has recently been appointed director of research of the American Electro Metal Corp., Yonkers, N. Y.

White Aircraft Corp., Palmer, Mass., announce that **Roger W. Griswold, Jr.**, formerly vice-president and director of the Griswold Mfg. Co., Erie, Pa., is now associated with them as vice-president and director.

Charles Briggs is now factory manager and **James L. Erickson** director of sales and engineering of the newly formed Lukens Aluminum Co., Dayton, Ohio, aluminum alloy die casting plant.

J. L. Balleny, secretary of the Ontario Chapter A.S.M. for the past three years, has been transferred from manager of the industrial heating section, supply department of Canadian General Electric Co., Ltd., to manager of the local office in Trail, B. C.

A. B. Kinzel, vice-president of Union Carbide and Carbon Research Laboratories, Inc., and Campbell lecturer for 1947, has been re-elected chairman of the Engineering Foundation for the coming year.

A. F. Gallistel, Jr., formerly plant manager of Thomas and Skinner Steel Products Co., Indianapolis, and superintendent of the metal plant of Streater Industries in Spring Park, Minn., has recently joined the Argus Camera Co. as plant engineer in Minnesota.

POWDER METALLURGY
asks no favors
There was a time when manufacturers thought of powder metallurgy as just a "neat trick." They said, in effect: "That's very clever and no doubt difficult, but what can it do for me?"
Here at Moraine Products, we've worked to put powder metallurgy on a realistic foundation. We've made it stand on its own feet in dollars-and-cents competition with other methods of producing parts. And a growing list of large users proves that metal powder parts by Moraine fill a real need in today's industrial requirements.
Can metal powder parts by Moraine save you money? There is a good chance they can if the parts you need fulfill these conditions: 1) The shape permits good die fill and proper density; 2) the order is sufficiently large to justify initial tooling costs; 3) the physical properties and tolerances required are within the range attainable in normal factory production. Get a straight answer from Moraine Products.
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MORAINE PRODUCTS
DIVISION OF
GENERAL MOTORS
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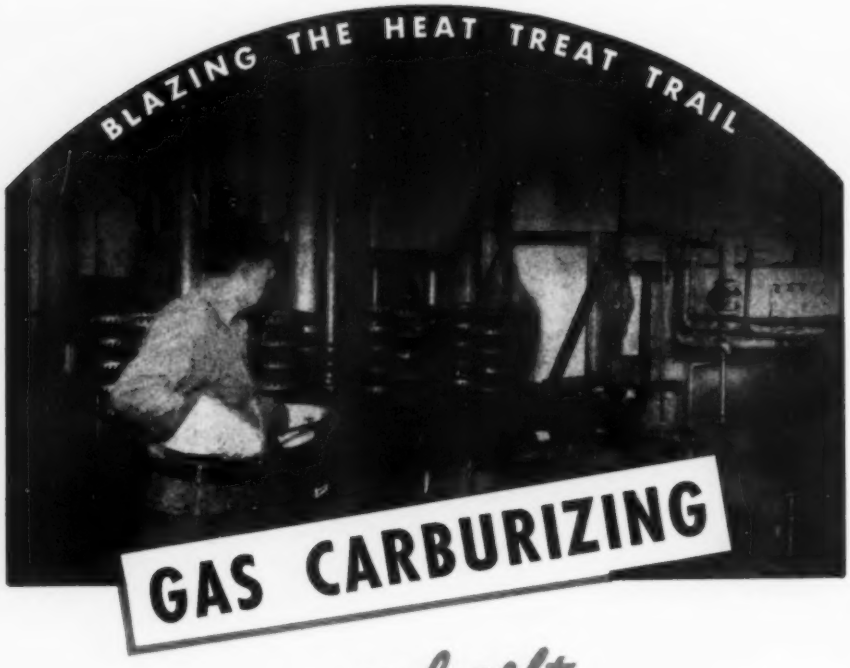

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MORE ACCURATE, LOWER-COST CASE HARDENING

HOLCROFT engineers established the basic principle on which *all* modern gas carburizing furnaces operate—namely, that in order to control the process, a non-decarburizing gas must be used to dilute the hydrocarbon gases which supply the carbon for carburizing. In order to *apply* this principle, Holcroft & Company in 1935 designed and built a generator to produce such a diluting gas.

This patented development—resulting from original Holcroft research—brought all the advantages of today's gas carburizing process. These include (1) accurate control of case depth and carbon content; (2) exceptionally clean, soot-free work; (3) a notable increase in furnace alloy and tray life; and (4) greater output with much less labor. Because of these advantages, gas carburizing is rapidly replacing pack carburizing throughout industry.

Further details on the process are given in the Holcroft Gas Carburizing bulletin, available on request.

The Holcroft engineering leadership which developed gas carburizing is available to serve YOU in production heat treat work of every kind. And remember—Holcroft offers you COMPLETE METALLURGICAL AND ENGINEERING SERVICE, from designing the furnace to your individual needs through the trial run in your plant. We invite your inquiries.

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5724 Navigation Blvd.

Canada: Walker Metal Products, Ltd., Walkerville, Ontario

Personals

Formerly associated with Sturdivant Metal Products Co., **Ralph Parkman** is now doing graduate work in metallurgy at Stanford University.

Robert F. Benedick is now employed by North American Aviation, Inc., Los Angeles.

L. Mark Irwin, formerly process chemist of Solar Aircraft Co., is now attending graduate school, department of metallurgy, University of Minnesota, Minneapolis.

Dana W. Smith, previously with Glenn L. Martin Co., is now chief metallurgist in the research department, fabricating division of the Permanente Metals Corp., Spokane, Wash.

James V. Carroll has returned to the Aluminum Co. of America, Massena, N. Y., as metallurgical engineer.

N. J. Wells is currently with the International Harvester Co., manufacturing research department, as metallographer.

Murray A. Schwartz is now employed by the N.E.P.A. Project, Fairchild Engine & Airplane Co., Oak Ridge, Tenn., as a ceramic engineer.

John A. Sulick has been appointed purchasing agent for the Palmer Manufacturing Co., Cleveland.

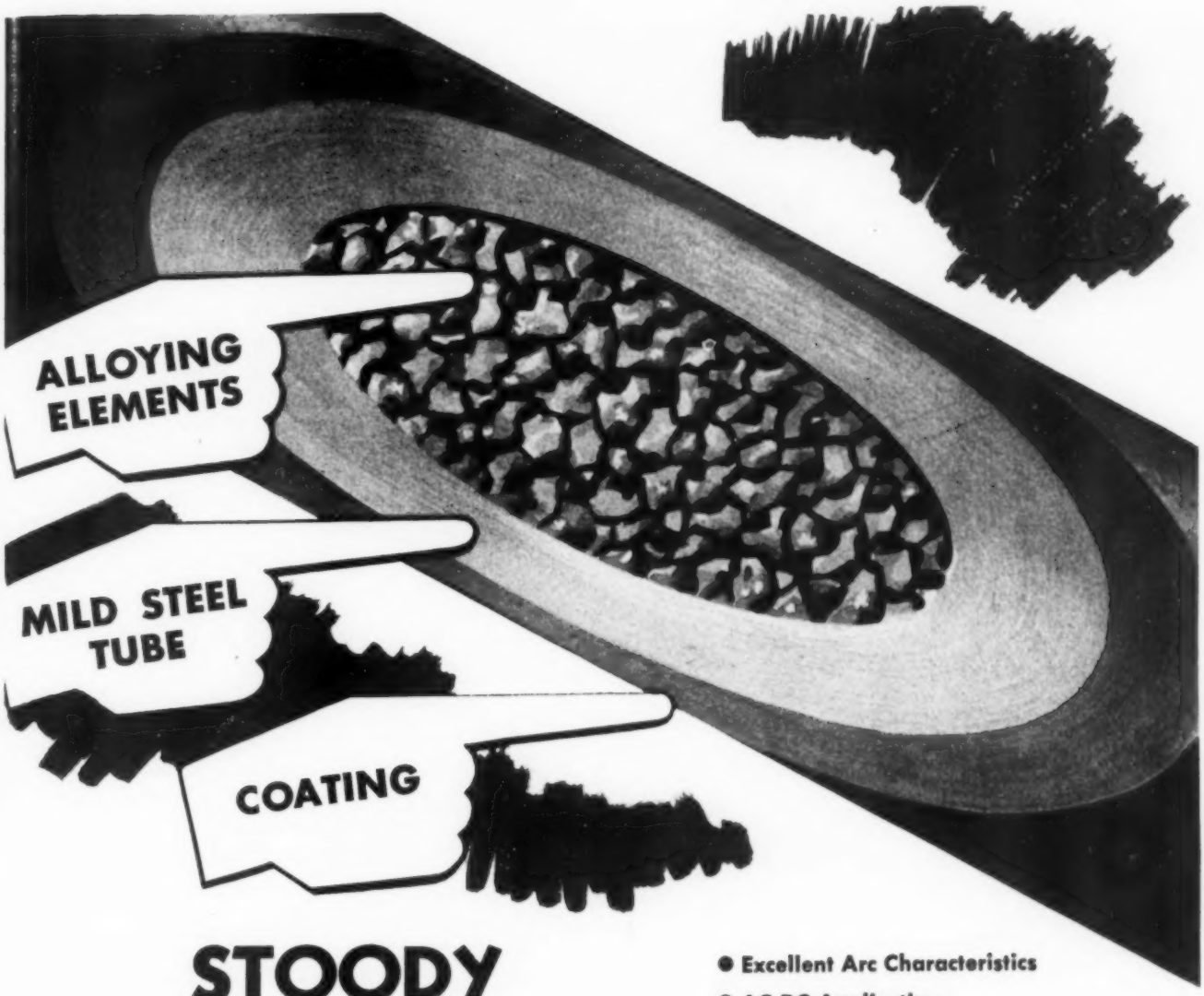
Paul W. Kloeris, Jr., is metallurgist with Permo, Inc., Chicago.

Holmes C. Williams has been elected president of Electronic Power, Inc., Chicago, manufacturers of changeable neon signs. Mr. Williams was formerly sales manager of the company.

C. G. Hopewell has been made superintendent of Automatic Control Engineers, Inc., Bedford, Ind., manufacturers of fractional horsepower motors.

After five years as chief chemist and metallurgist at Fairchild Aircraft Div., **Francis W. Brown** has been made head of the chemistry department of Hagerstown (Md.) Junior College, where he will organize a department in metallurgy.

Fritz V. Lenel, formerly metallurgist with Moraine Products Div., General Motors Corp., has joined the staff of Rensselaer Polytechnic Institute as assistant professor of metallurgical engineering.



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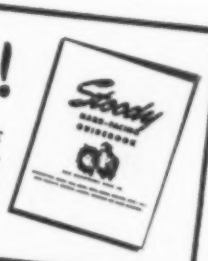
Shows 125 proven applications for retarding wear and increasing equipment life with Stoody Self-Hardening and other Stoody Alloys. Sent free—write today.



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23 FEET of a 19 INCH *Centrifugally* CAST "CARTRIDGE"

It's alloyed to meet a highly corrosive condition. It's centrifugally cast to give it the higher strength and greater metal density to meet a tough structural requirement. It's typical of what we can do in our centrifugal casting department. In this case two sections were made and welded together.

May we suggest that if you have need for any high alloy pipe or tube ranging in diameter from 2½ inches to 24 inches and, depending on diameter, up to 15 feet in length, you look into our centrifugal casting service.

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Personals

Formerly metallurgist for Hyatt Roller Bearing Div., General Motors Corp., **Sidney H. Avner** is now teaching drafting and descriptive geometry at Queens College, Flushing, N. Y., and at City College in New York.

J. B. Mohler is now director of research with the Johnson Bronze Co. of New Castle, Pa.

R. B. Gunia has been transferred by Carnegie-Illinois Steel Corp. from manager of the stainless steel bureau, metallurgical division, Chicago, to assistant metallurgical engineer for stainless steels in Pittsburgh.

Chin-Tse Yang has joined the faculty of the University of California as lecturer in mechanical engineering and will continue graduate study toward a doctorate.

W. Harrison Lackey has been transferred by Lukens Steel Co. from sales representative in the York territory to district manager of sales in the Pittsburgh district.

S. L. Channon has come to the United States from Australia to accept a research fellowship at the University of Utah. He was previously metallurgist in charge of the metallurgical laboratory in the Commonwealth Government Small Arms Factory, Lithgow, N.S.W.

E. C. Hart, Jr., is now plant metallurgist for Alloy Steel & Metals, Los Angeles.

James Baxter has accepted the position of metallurgist and melting supervisor at Columbia Malleable Casting Division, Grinnell Corp., Columbia, Pa.

Wallace E. Gall has been transferred by the Swan Finch Oil Corp. from the northern Illinois territory to the Iowa territory.

R. G. Sault, vice-president of Porter Forge & Furnace, Inc., Somerville, Mass., has been elected president of the Metal Treating Institute; **Rowland H. Starr** of Starr Heat Treating Co., Detroit, is vice-president; and **R. W. Thorne** of Bennet Steel Treating Co., Newark, N. J., is treasurer.

Metal Powder Association announces the election of **H. E. Hall**, president, Metals Disintegrating Co., as its president and **Robert L. Ziegfeld** as secretary-treasurer.

NOW

POURING TEMPERATURE MEASUREMENT

made *practical*

It's nothing new to foundry men that correct pouring temperature means better castings and increased production. The need has been for a really practical portable temperature measuring system for non-ferrous foundries.

At last this need has been fulfilled. The Brown system which features the ElectroniK indicating and recording instrument and a portable molten metal thermocouple has given highly satisfactory service in the many foundries where it has been installed.

The ElectroniK instrument is fast and accurate. As soon as the thermocouple is immersed in the metal, the instrument pointer swings to the proper temperature reading. All this happens within ten seconds. Workers are not delayed, yet accurate pouring temperatures can be maintained.

The giant scale is another reason why the Brown ElectroniK is so convenient for foundry use. You don't need to bring the crucible to the instrument; temperatures can be read at a distance.

The Brown ElectroniK with the portable molten metal thermocouple can bring you all the advantages of uniform pouring temperatures with the speed and convenience necessary in foundry operations. For complete information on this system, write for Data Sheet 5.4-2 and Catalog 15-11.

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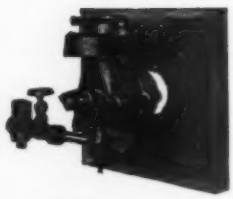
BROWN *ElectroniK* POTENTIOMETERS

JOHNSTON

BLOWERS

LOW PRESSURE, DIRECT CONNECTED
Simple, efficient, compact, dependable.

BURNERS



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Mixes ALL the fuel with ALL the air.

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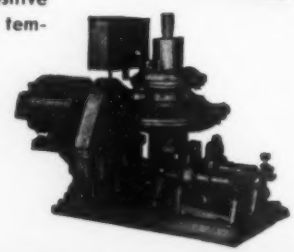
VALVELESS AUTOMATIC. Positive control of oil feed. Straight line temperature control.

FURNACES



for Forging, Heat Treating, Soft Metal Melting.

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Warren's Propane and Butane, the versatile, low-cost, high-purity fuels, are the most effective and economical fuels for industrial and domestic use.

Warren is a pioneer in the Liquefied Petroleum Gas industry and is backed by veteran experience, engineering and technical skills and modern plants. This insures uniform high quality fuel for consistent operating performance, maintained production and greater profits.

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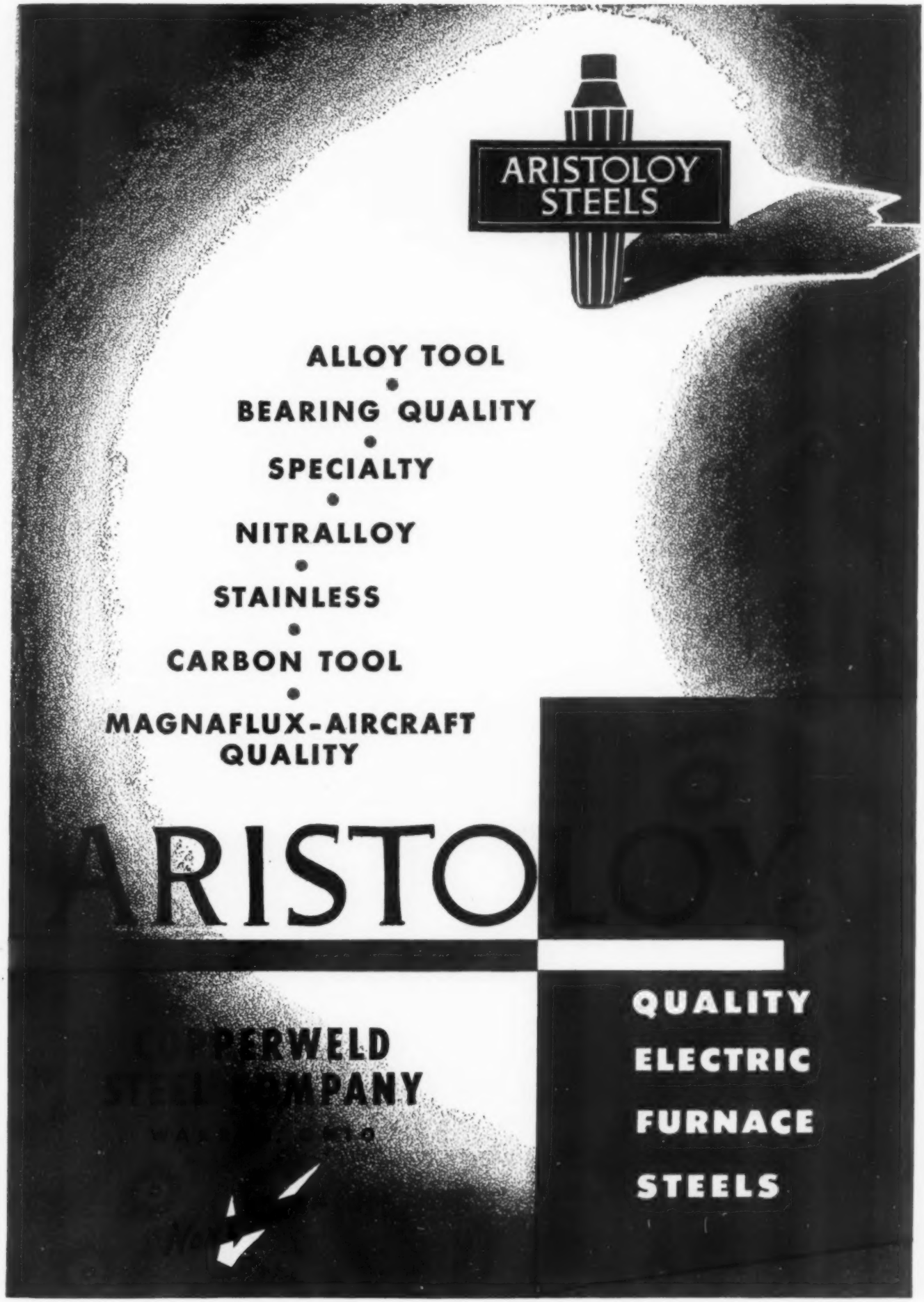
Thorium for Atomic Power*

IT LOOKS fairly simple to design a graphite pile for the generation of energy by a fission chain reaction. Such a power plant has been described by the Atomic Energy Commission (see *Metal Progress* for December 1946, p. 1204). A large pile of graphite blocks and uranium rods would be spaced in such a way that the fast neutrons generated during the natural decay of U^{235} should be slowed down to thermal speeds by enough graphite so they become readily captured by other U^{235} atoms (with immediate fission resulting.) This is the essential of the chain reaction. The energy resulting could be removed as heat by a stream of cooling water.

However, natural uranium (a mixture of U^{238} and U^{235}) is so active chemically that the rods have to be protected by a thin but absolutely gas-tight sheath of a metal, itself corrosion resistant, a good heat conductor, and of very low ability to capture neutrons. Highly purified aluminum is, as far as is now known, the only suitable metal for this purpose. Each "canned" rod of uranium is set concentrically in a somewhat larger aluminum tube, and cooling water flows through the narrow annulus.

But can such a pile, using normal uranium (that is, 99.3% U^{238} and 0.7% U^{235}) and water to remove the heat, produce useful power? The answer is, "Not in the present state of our knowledge and probably, so far as we can see, not even in the future". To produce power, the water in the circulating system must be under considerable pressure. The outer aluminum tube has therefore got to be made thick enough to withstand this pressure, and the extra weight of this slightly, but still definitely, neutron-capturing material will upset the balance and prevent the fission chain from being set up. Apart from this, no engineer would choose aluminum *(Cont. on p. 1018)*

*Abstracted from "Metallurgical Problems Involved in the Generation of Useful Power From Atomic Energy", by Sir Wallace Akers, director of research, Imperial Chemical Industries, Inc. 37th May Lecture to the Institute of Metals. *Journal* of the Institute of Metals, V. 73, Part II, 1946-47, p. 667.


ARISTOLOY STEELS
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BEARING QUALITY
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SPECIALTY
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NITRALLOY
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CARBON TOOL
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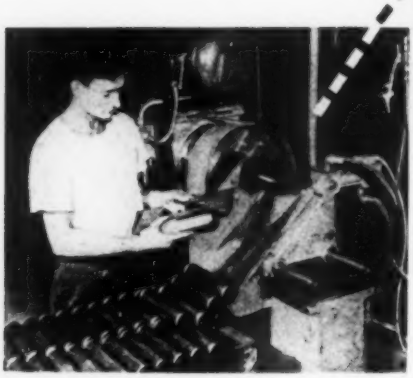
ARISTOLOY
QUALITY
ELECTRIC
FURNACE
STEELS

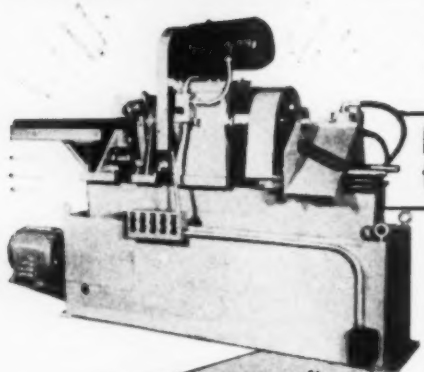
575 TUBES CUT-OFF Per Hour



Pines Machine Cuts to .004" Tolerance in Length

A prominent manufacturer of automotive parts uses the Pines Cut-Off Machine to cut 575 pieces of 2¼" x .065 steel wall tubing per hour. Previous production for the same operation on other equipment produced only 70 pieces per hour. In addition, the Pines Cut-Off Machine assures greater accuracy length to .004" tolerance and permits the operator to handle other work.

The operator simply initiates continuous operation by starting a long piece of tubing through the motor driven feed rolls. The finished parts are discharged into a container as the tube is automatically cut-off to the desired length.



Fast-Acting, Simple Operation Reduces Cost per Piece

The Pines Cut-Off Machine is the **simple automatic** way to cut pipe or tubing to accurate lengths rapidly. The machine only requires the operator to set the tools and supply it with stock.

The average time to complete a machining cycle is 1½ seconds. Pines Cut-Off Machines can produce 1500 pieces per hour depending on material, diameter, wall thickness, length and type cut desired. Adjustable stop target determines cut-off length and may be quickly set to suit job requirements.

Pines Engineering Service can assist you on your tubing and pipe cut-off problems. There is no obligation for this assistance.

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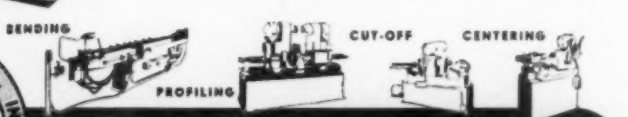


PINES ENGINEERING CO., Inc.

Specialists in Tube Fabricating Equipment

672 WALNUT AURORA, ILLINOIS

Thorium for Atomic Power

(From p. 1016) for boiler tubes! But there are promising possibilities of obtaining useful power from a graphite-uranium pile, if one abandons water as the heat transfer medium, and uses a gas of suitable thermal properties and low neutron-capturing ability (such as helium) or a liquid (such as bismuth) of similar properties.

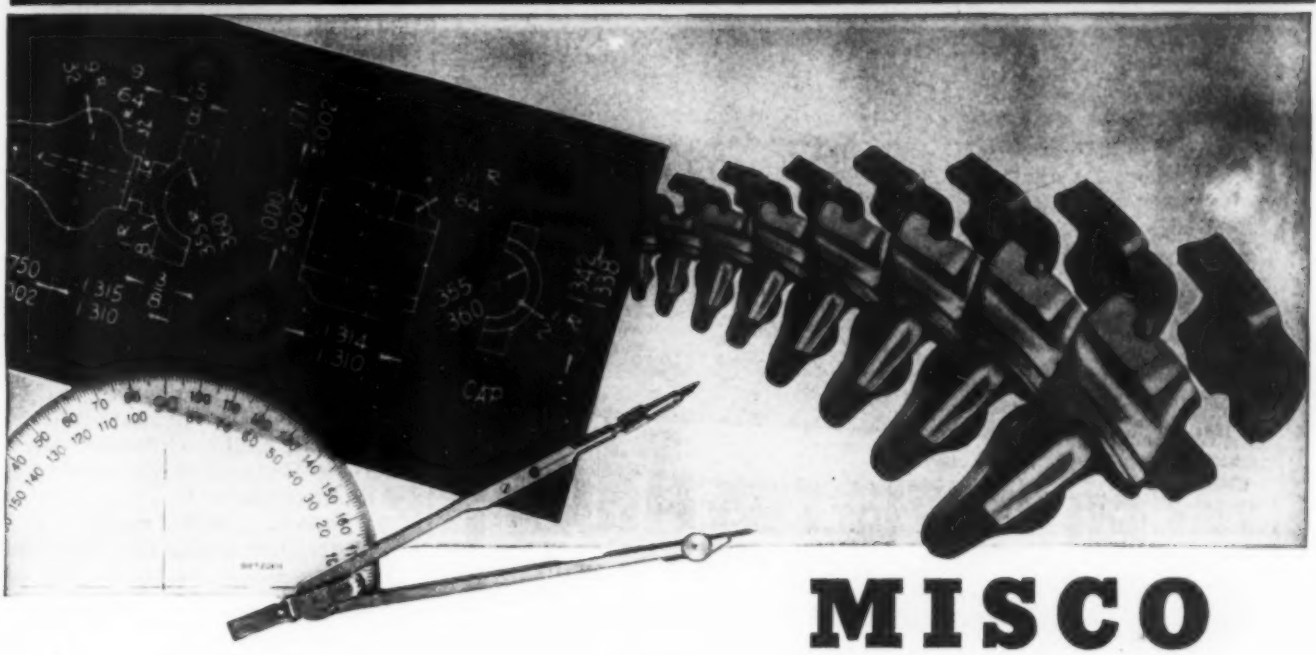
Evidently much greater latitude in design becomes possible if we can make the neutron balance between those generated and those recaptured by U^{235} a little less delicate — if we can use, instead of natural uranium, a mixture containing a rather larger content of fissile material. Addition of U^{235} separated from natural metal has been suggested. Such separation of isotopes has been done in two plants in America for manufacture of explosive metal, but the overhead and operating costs of these plants are probably too high for economical use as a fuel generator. But there is another route. After a graphite pile has been working for a reasonable period, the uranium rods will have lost some of their U^{235} but will contain, instead, a certain amount of plutonium, Pu^{239}, a new chemical element, derived from the otherwise inert U^{238} by neutron capture. The separation of this plutonium by chemical means, while difficult, is likely to cost substantially less than the separation of U^{235} by purely physical means.

Replacement of the U^{235}, as it is "burnt up" in an ordinary pile, by the equally fissile plutonium, has a vitally important bearing on the availability of supplies of fissile fuel. If the U^{235} be not replaced, the effective fraction of ordinary uranium available for power generation will be some part of the original 0.7% which is represented by U^{235}. After some part of this has been used up in the fission process, the fraction remaining will be too small to ensure that one fission neutron finds a U^{235} nucleus for every nucleus which undergoes fission. In fact, the fission chain will stop.

If, however, the mixture of U^{235} and U^{238} is enriched, and the design permits such an operation that of the, say, 2½ neutrons produced by each atom of U^{235} which breaks up, one neutron finds another U^{235} nucleus to carry on the chain, and one is captured by U^{238} to form Pu^{239}, *(Turn to p. 1020)*

MISCO *Precision* CASTINGS

CAST TO MICROMETER TOLERANCES



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Misco Precision Castings are now available to help you mass-produce the part *best suited for the job*. Design engineers need no longer compromise because of the limitations of conventional methods of manufacture. The bracket support and cap, illustrated above, are splendid examples of Misco's ability to produce in large quantities the part which the *designer* wanted but which would have been uneconomical to mass-produce by yesterday's manufacturing methods. Made to the highest aircraft material specifications the customer realized a considerable saving due to the complete elimination of forging die expenses and greatly reduced tooling costs. Further savings resulted from a substantial reduction of finishing operations.

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Three pieces house the rotors of a Type QH Gerotor Hydraulic Pump designed for speeds of 1200 r.p.m. and up, and operating pressures of 1200 p.s.i. continuous and 1500 p.s.i. intermittent. And for those three pieces — a head, a body and an intermediate eccentric ring — the Gerotor May Corporation of Baltimore, Md. selected castings of Meehanite as made by Brake Shoe.

This 3-piece construction means protection for the pump's operation because the Meehanite metal offers a combination of the service characteristics demanded — pressure tightness, vibration dampening and strength — plus the manufacturing advantage of ready machinability.

For piloting castings, American Brake Shoe Company maintains at its metallurgical department a complete foundry devoted solely to experimental work by a staff of engineers and metallurgists. And in actual production, Brake Shoe applies its experience-based casting techniques in its foundries at Mahwah, N. J., Melrose Park, Ill. and Baltimore, Md. At this trio of plants we produce widely used types of castings (light or heavy weight, molded in green or dry sand or all core assemblies) including intricate and special types. Write and tell us the castings you need and the job they must do.

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BRAKE SHOE AND CASTINGS DIVISION
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Thorium for Atomic Power

(Starts on p. 1016) then, for every U^{235} nucleus which is burnt up, one new fissile plutonium nucleus will be produced, so that the total number of fissile nuclei remains always the same, whereas the much more abundant U^{238} nuclei are gradually disappearing. In fact the percentage of fissile nuclei will be rising steadily above the 0.7% of natural uranium, while the U^{238} (ordinarily thought of as being an inert diluent) will be steadily burnt up.

While this is a distinct possibility, no information has yet been published about this phase of neutron economy. It may be that some of the products of radioactive decay have rather high neutron capture; if so, the uranium in the heat generator would have to be cycled through a proper purification plant, which of course would increase the cost of the operation of a power plant.

Thorium, $_{90}Th^{232}$, which is a good deal less scarce than uranium in nature, has an atomic weight of 232 and has 90 protons in its nucleus, compared with the 92 in uranium. It resembles $_{92}U^{238}$ in not being fissile but in being able to capture a neutron, whereupon such an atom undergoes two stages of radioactive decay with the conversion of two neutrons, in the nuclei, to protons. The result is that $_{90}Th^{232}$ becomes $_{92}U^{233}$; in fact, a new isotope of uranium is produced. This isotope resembles $_{92}U^{235}$ in undergoing fission when it captures a neutron. Also, being an isotope of uranium, it is chemically different from thorium and so can be separated fairly readily from the unchanged thorium by various processes of solution and precipitation.

It is possible to prepare this new isotope U^{233} by placing thorium, or a suitable thorium salt, in the outer layers of a graphite-uranium pile so that it is exposed to bombardment by the neutrons which would otherwise escape. If enriched uranium be used in the pile, then more thorium can be inserted into the system without stopping the chain reaction through too great a capture of neutrons by the thorium. But unless graphite-uranium piles can be worked in such a way that at least the U^{235} burnt up can be replaced by plutonium, this use of thorium would seem to get us no further than before, because *(Cont. on p. 1022)*

Products for the Iron and Steel Industries

PRODUCT	TYPICAL COMPOSITION	APPLICATIONS
ALSIFER	Aluminum.....20% Silicon.....40% Iron.....40%	Used principally as a steel deoxidizer and for grain size control.
FERRO CHROMIUM High Carbon Grade	Chromium....66-70% Carbon.....4-6%	For wrought constructional steels and steel and iron castings.
Iron Foundry Grade	Chromium....62-66% Carbon.....4-6% Silicon.....6-9%	For alloyed cast irons. Readily soluble as a ladle addition at the lower temperatures of cast iron.
Low Carbon Grades	Chromium....67-72% Carbon...06%, .10%, .15%, .20%, .50%, 1.00% and 2.00% max.	For low carbon chromium steels, especially those with high chromium content, such as stainless and heat-resistant types.
FERRO SILICON 25-30% Grade	Silicon.....25-30%	Deoxidizer for open hearth steels; also for high silicon, corrosion-resistant iron castings.
50% Grade	Silicon.....47-52%	Used as a deoxidizer and for the addition of silicon to high silicon steels, for springs, electrical sheets, etc. Pulverized form used as ladle addition to cast irons for silicon content and graphitization control.
75% Grade	Silicon.....74-79%	For high content silicon steels, such as spring steels, sheets and forgings of high magnetic qualities for electrical apparatus.
High Silicon Grades 80-85% 85-90% 90-95%	 Silicon.....80-84.9% Silicon.....85-89.9% Silicon.....90-95%	 For high content silicon steels where small ladle additions are used for required silicon content. Also for manufacture of hydrogen by reaction with caustic soda and production of magnesium by the Pidgeon process.
FERRO TITANIUM High Carbon Grade	Titanium.....15-18% Carbon.....6-8%	Final ladle addition to control "rimming" action and to clean effervescing steel. Final deoxidizer and scavenger for steel castings and fully killed ingot steels.
Medium Carbon Grade	Titanium.....17-21% Carbon.....3-4.50%	Often preferred to the High Carbon Grade as a final ladle addition to very low carbon rimming or effervescing steels.
Low Carbon Grades 20-25% Ti Grade	Titanium.....20-25% Carbon...max. 0.10% Silicon.....max. 4% Aluminum max. 3.50%	Carbide stabilizer in high chromium corrosion-resistant steels of extremely low aluminum content. Deoxidizer for some casting and forging steels.
40% Ti Grade	Titanium.....38-43% Carbon...max. 0.10% Silicon.....max. 4% Aluminum...max. 8%	Carbide stabilizer in high chromium corrosion-resistant steels, where smaller ladle additions are desired and extremely low aluminum content is not essential.
VANADIUM METAL 90% Grade	Vanadium....91.15% Aluminum.....2.25% Silicon.....0.50% Carbon.....0.17%	For special iron-free (nonferrous) or low iron alloys or low impurity ferrous alloys.
95% Grade	Vanadium....95.18% Aluminum.....2.00% Silicon.....0.27% Carbon.....0.40%	Principally for research on the properties of pure alloys, where very low iron content is essential.

PRODUCT	TYPICAL COMPOSITION	APPLICATIONS
FERRO VANADIUM Grade "A" (Open Hearth)	Vanadium....35-40% Silicon.....max. 12% Carbon...max. 3.50%	For low percentage vanadium content of rolled, forged or cast constructional steels. Also used in vanadium cast irons.
Grade "B" (Crucible)	Vanadium....35-45% Silicon...max. 3.50% Carbon...max. 0.50%	For tool steels and special high vanadium steels in which required limits for carbon and silicon are narrow.
Grade "C" (Primos)	Vanadium....35-45% Silicon...max. 1.25% Carbon...max. 0.20%	For tool steels and special steels requiring high percentages of vanadium and exceptionally low carbon and silicon content.
High V Grades	Vanadium....50-55% 60-65% 70-80% Silicon.....Low Carbon.....Low	For special applications and uses requiring large vanadium additions.
VANADIUM PENTOXIDE Technical Grade Fused Form	V_2O_5.....90%	A source of vanadium in basic electric furnace steels. A base for numerous chemical compounds.
Technical Grade Air Dried Form	V_2O_5.....83-85%	A base for preparation of numerous chemical compounds (catalysts, etc.).
GRAINAL ALLOYS Vanadium Grainal No. 1	Vanadium....25.00% Aluminum....10.00% Titanium.....15.00% Boron.....0.20%	Practical and economical intensifiers for controlling and increasing the capacity of steels to harden, and for improving other important engineering and physical properties.
Vanadium Grainal No. 5	Vanadium....13.00% Aluminum....12.00% Titanium.....20.00% Boron.....0.20%	See above.
Grainal No. 79	Aluminum....13.00% Titanium.....20.00% Zirconium.....4.00% Manganese....8.00% Boron.....0.50% Silicon.....5.00%	See above.
GRAPHIDOX No. 4	Silicon.....42-46% Titanium.....9-11% Calcium.....5-7%	For graphitization of iron; ladle treatment insures normal graphite, free from dendritic structure; reduces chill; efficient inoculant in production of high strength irons.
V-FOUNDRY ALLOYS V-5 Grade	Chromium....38-42% Silicon.....17-19% Manganese....8-11%	Used in cast irons as a ladle addition. Reduces chill, promotes uniformity of structure, increases strength and hardness.
V-7 Grade	Chromium....28-32% Silicon.....15-21% Manganese...14-16%	See above.
BRIQUETTES Ferro Chromium	Hexagonal. Weigh approx. 3¾ lb. and contain 2 lb. of chromium.	A practical and convenient form for adding ferro-alloys to the cupola.
Ferro Silicon	Two sizes, both cylindrical, one containing 1 lb. of silicon; the other, 2 lb. of silicon.	See above.
MISCELLANEOUS	Special ferro-alloys, metals, chemicals and carbides.	To meet individual requirements.

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1450 Buffalo Avenue Niagara Falls, N. Y.

Thorium for Atomic Power

(Starts on p. 1016) some of the neutrons which might be used to produce plutonium from U^{238} in a very large pile will be used instead to produce U^{233} from thorium. The net result will be that some thorium will be converted into fissile U^{233}, but an equivalent amount of U^{238} will be left as an inert substance.

The production of U^{233} in place of plutonium at this stage may, however, lead to a real gain. There seems to be a possibility, and quite a good one, that the number of neutrons ejected when U^{233} undergoes fission, together with neutron capture of thorium, may make it possible to build a pile containing U^{233} and thorium in which *more* nuclei of U^{233} are formed than are burnt up, so that the supply of U^{233} will be continually increased. We could then dispense with uranium and produce U^{233} and generate power, without any more natural uranium than we now have, using only thorium as our raw material. Furthermore, this would enable us to go back and burn up, by conversion of plutonium, any U^{238} which might have been dumped because the neutron economy had been too low to allow U^{235} to be replaced by Pu.

So-called "secondary reactors" of enriched uranium (such as described briefly above) could be made smaller and smaller with the degree of enrichment. The limit is the bomb. Most references to secondarily enriched piles seem to overlook an essential point in regard to neutron economy. This is seen, in its simplest form, in secondary reactors with natural uranium enriched with U^{235} up to, say, 5%. With such a material, quite a small reactor could be worked despite substantial loss of the fission neutrons, but other natural uranium would be needed to produce the U^{235} to enrich the uranium for the reactor, and this would inevitably mean that a large quantity of uranium would be so impoverished in U^{235} that it would have to be dumped. In fact every neutron wasted from the secondary reactor means one atom of U^{238} dumped as useless waste material. The same applies to enrichment with plutonium.

It may be that the thorium-U^{233} system will be capable of "breeding" U^{233}; there will then be neutrons to spare for wasting in an enriched secondary reactor.

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John L. Morosini

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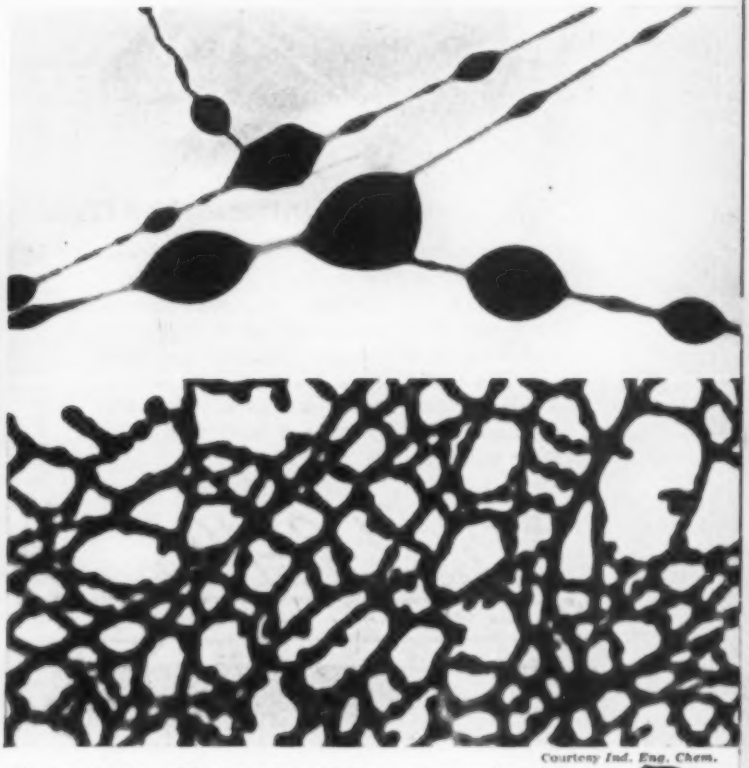
Cast iron from crane wheel magnified 2,000 times.



Courtesy Ind. Eng. Chem.

Above, fresh milled rubber. Below, after vulcanization. Magnifications 100,000 times.

Turn to...

photomicrography
for magnifications up to 2,000 times

electron micrography
for magnifications up to 100,000 times

IN many production problems, the smaller the details you can see, the more you realize their importance. It's the detail seen in a photomicrograph or an electron micrograph that often explains why some materials do their job and others don't.

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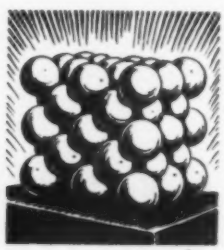
X-Ray and Electron Beams

(Continued from page 990)

A special tube has generally been employed in the Lonsdale technique. In Dr. Geisler's method, this divergent beam apparently originates at the sample as secondary radiation. By using single crystals of alloys containing iron and cobalt, prominent patterns of white and black lines were caused by the diffraction of the secondary divergent radiation when these single crystals were exposed to copper radiation by the transmission Laue method. In order to apply this method to other materials, an intermediate radiator, such as iron oxide, is applied to the surface of the specimen and acts as a source of secondary divergent radiation.

Interstitial compounds came into the purview of the conference through two papers, the first of which (by W. J. Kirkpatrick of Mellon Institute) gave a brief résumé of the modern theory of interstitial compounds, together with their definition and classification. R. E. Rundle, of Iowa State College, then presented a new interpretation of these compounds based on the directional properties of the bonds in terms of bidirectional p-orbitals and electron-deficient bonding. His talk was confined mainly to the interstitial carbides and nitrides of the formula MX, where the intermetallic distances are usually larger than the corresponding distances in metals, and nearly all of which have the sodium chloride structure. He pointed out that solution theories fail to account for the greatly increased hardness and melting points of these compounds, and that strong metal-nonmetal bonds have to be considered. Such considerations have allowed Dr. Rundle to predict the metals which form such compounds. To the metallurgists, this paper gave promise that powerful methods other than thermodynamics are not being neglected in the attempt to predict the properties of alloys.



Q-ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION X-ite

ETER BLACKWOOD, Scot, Philosopher, Foundryman

— *The world beat a path to his door.*

ARE among many is a philosopher, a deep thinker in science, living in mechanized production who, weighing the crustation of precedent termed "knowledge", finds the simple TRUTH and makes it WORK.

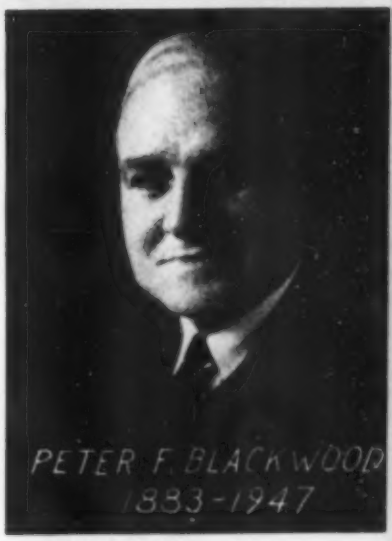
ARER still is such a man, rich in the humanities, dispensing kindly help and inspiration to all whose lives touched his.

UCH a man was Peter Forbes Blackwood, late Foundry Superintendent of the Ford Motor Company of Canada, to hose plant came more foundrymen, industrialists and military technicians seeking knowledge of the art of casting metals an to any foundry in history. They came, wondered, learned. Much that they saw was so simple, so logical that it as *obscured by its clarity* from the professional mind.

ISTORICALLY, "Pete" was born in Lanarkshire, Scotland, in 1883. He attended Gilbeorehill College and Glasgow niversity. He completed a cost accounting course at the West Scotland Technical School and was apprenticed to the onaldson Iron Works, Ltd. Following this apprenticeship, he sat for his London and City Guild examination and passed ith high honors.

E then traveled Europe and North Africa on metallurgical surveys before coming to America in 1910 where he joined his other Alex to pioneer in the operation of electric steel foundries.

N 1918 he became metallurgical supervisor for foundries of Ford Motor Company of Detroit. From 1920 until 1924 was foundry superintendent of Pontiac Motors. For ten years from 1924 he was foundry superintendent of General Motors, Buick Motors Division.



IN 1934 he became superintendent of the new foundry of the Ford Motor Company of Canada, designed to cast crankshafts alone. His operation so prospered that plant expansion carried through World War II. The Canadian Ford industry was swamped. The British Empire made heavy demands. Peter Blackwood met them by vastly improved methods of centrifugal casting. He produced aircraft cylinder barrels, gears and sprockets and jet engine parts in great quantity to the highest specification. Fourteen electric furnaces were added to the iron foundry. They produced 450 tons of steel daily. Production was piloted by the finest experimental foundry set-up on earth, equipped with induction furnaces, electronic arc furnaces, with vacuum and refrigeration equipment and with a battery of Blackwood centrifugal casting machines.

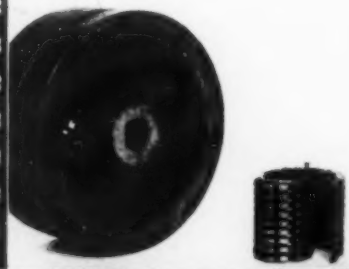
WE had the rare privilege of working closely with Peter Blackwood. He said: "Bring me your tough nuts and I'll try to crack them." He went further, training men for us, sending us help. Pete considered most foundry processes obsolete. Together we worked in devising new methods. When Pete was taken sick, we were pooling ideas for casting improvements. "A forging is only a casting that has been badly abused", said Pete. "We've got to teach castings to stand on their hind legs and speak out on their obvious points of superiority." Many men are now laboring to make Pete's dream come true.

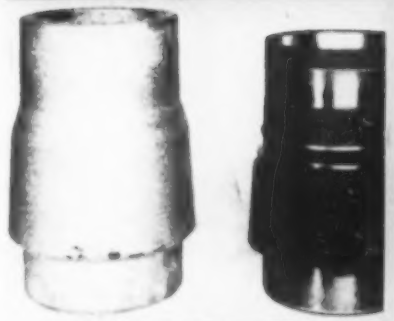
IN 1946 the American Foundrymen's Association presented Peter Blackwood with the John H. Whitney Gold Medal of the A.F.A. for his development work with centrifugal castings. He got an equally big kick out of a bunch of Scotch Heather which we flew in for the occasion.

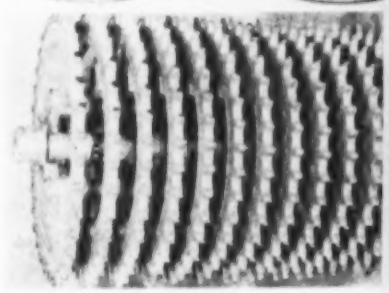
PETE'S able assistant, John Perkins, still in his thirties, rich in memory and inspiration, is carrying on as foundry superintendent. A game leg kept us from Pete's funeral. John Perkins wrote: "Knowing Pete as you did, I think you would have appreciated the atmosphere at the funeral better than anyone I know. Sitting there listening to a Scotch clergyman telling in his rich brogue what was in store for Pete as he passed through the Valley of the Shadows almost made one think—'Lucky Pete'."

WE may not be able to justify Pete's confidence but we shall keep faith in our quest for TRUTH.

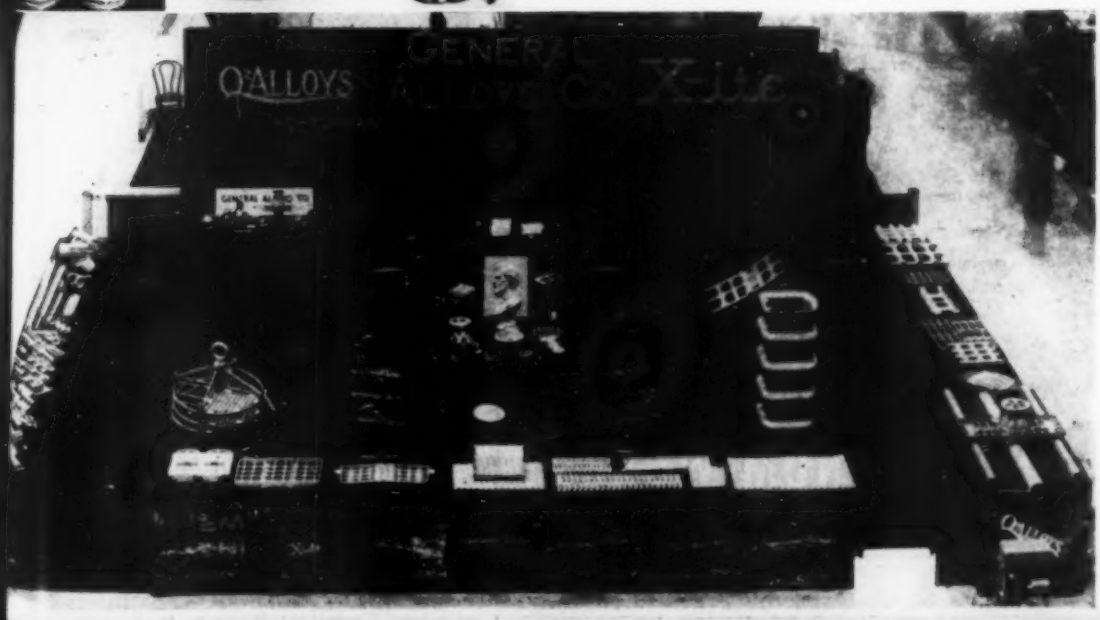
H. H. HARRIS







On the left is a centrifugally cast "Christmas Tree" of 192 castings on one gate. Next is an ingenious flexible pattern for casting milling cutters in tool steel. Top right is a centrifugally cast aircraft cylinder. Below that, a baker's dozen of motor transport "half-track" sprockets.



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Touch Welding*

THE GREAT difficulty in free arc welding has always been the fact that the distance between the electrode and the workpiece must be kept constant. In the past it has been found that with certain types of heavily coated electrodes, the coating can rest on the workpiece during welding (touch welding). Since these electrodes are expensive, and difficulties occur in welding because of the larger amount of slag, research work was carried out to perfect the properties necessary for touch welding while still retaining the good advantages and excellent mechanical properties of the base electrode.

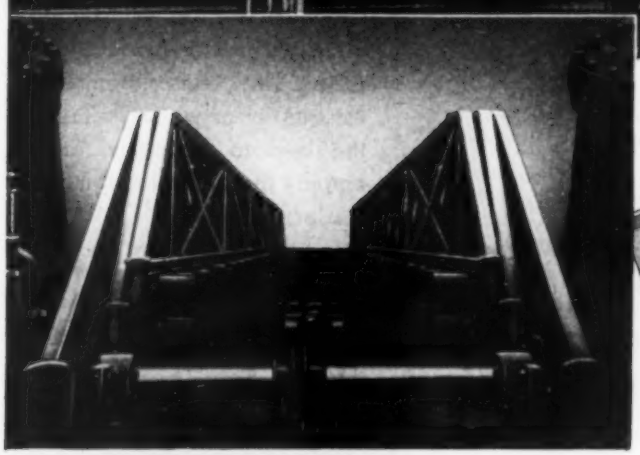
In the newly developed electrodes about half the metal of the core is transferred in finely divided form to the coating. The external diameter of the electrode is more than twice the diameter of the core, so the coating is extremely heavy. However, the core, which has to carry the current, must not be too thin; otherwise the resistance would be too high and the permissible arc current too low. The ratio of metal to slag may remain the same.

The ignition of the arc is much easier with this new electrode, because of the conductivity of the coating. When the coating is held against a definite spot on the workpiece, the current will rise rapidly and suddenly form an arc, thus automatically igniting the welding arc. The arc is usually ignited within 1 sec. Re-ignition after an interruption of a few cycles also takes place automatically. The advantage of contact arc welding, therefore, lies in the possibility of easy touch welding and the automatic ignition of the arc. Moreover, with a given current, the amount of metal deposited per unit time is considerably greater. The new contact electrodes also offer important advantages in welding with a free arc, where there is much less extinguishing of the arc even when the open voltage of the welding transformer is subnormal. Mechanical properties of the weld deposits are similar to those of the corresponding normal electrodes.

Welding from right to left is as simple as welding from left to right. Care must be taken to prevent the slag from running *(Cont. on p. 1028)*

*Abstracted from "Contact Arc Welding", by P. C. van der Willigen. *Philips Technical Review*, V. 8, June 1946, p. 161 to 166.

Firefighter With a Reach . . .



Courtesy American-LaFrance-Foamite Corp.

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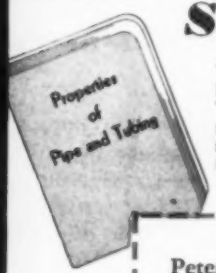

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Touch Welding

(From p. 1026) ahead of the arc. In the downhand position, an angle of 40 to 45° is best. If it is impossible to maintain this angle, it is possible to weld from right to left or to use a free arc.

A remarkable achievement is the ease with which overhead welding can be done. This is the most difficult position for welding and, as far as is known, it was never possible to apply touch welding with success in this position. With contact electrodes the deep cup of the coating gives better direction to the drops so that very little material falls to the ground. Experienced welders sometimes prefer to use a free arc in overhead welding.

In making a horizontal weld in the vertical plane, weaving is generally used to obtain a sufficiently wide bead. Therefore the great advantage of contact arc welding, namely, that no precise regulation of motion is necessary, does not apply, since free arc is always used in vertical-up welding. In vertical-down welding, the standard contact electrode gives rise to an excessive amount of slag, but a satisfactory contact electrode has been developed with a thinner coating.

Hot welding with high currents and heavy welding rods has not met with much success because the heavy electrodes tire the welder, much spatter and heat radiation occur, and difficulty is often experienced from undercut. Contact electrodes overcome all of these problems.

Hot Shortness of Al-Si Alloys*

HOT SHORTNESS of commercially-pure aluminum-silicon alloys was studied by casting and welding experiments. Each series consisted of refined aluminum, 99.5% Al, and eight alloys containing 0.25 to 12% Si, prepared from 99.5% Al.

The castings were made in an annular mold. Tensile stresses set up on freezing caused cracking in hot short alloys. The severity of the cracking *(Continued on p. 1030)*

*Abstracted from "Hot-Shortness of the Aluminium-Silicon Alloys of Commercial Purity", by A. R. E. Singer and P. H. Jennings. *Journal* of the Institute of Metals, V. 73, Part 4, 1946, p. 197 to 212.

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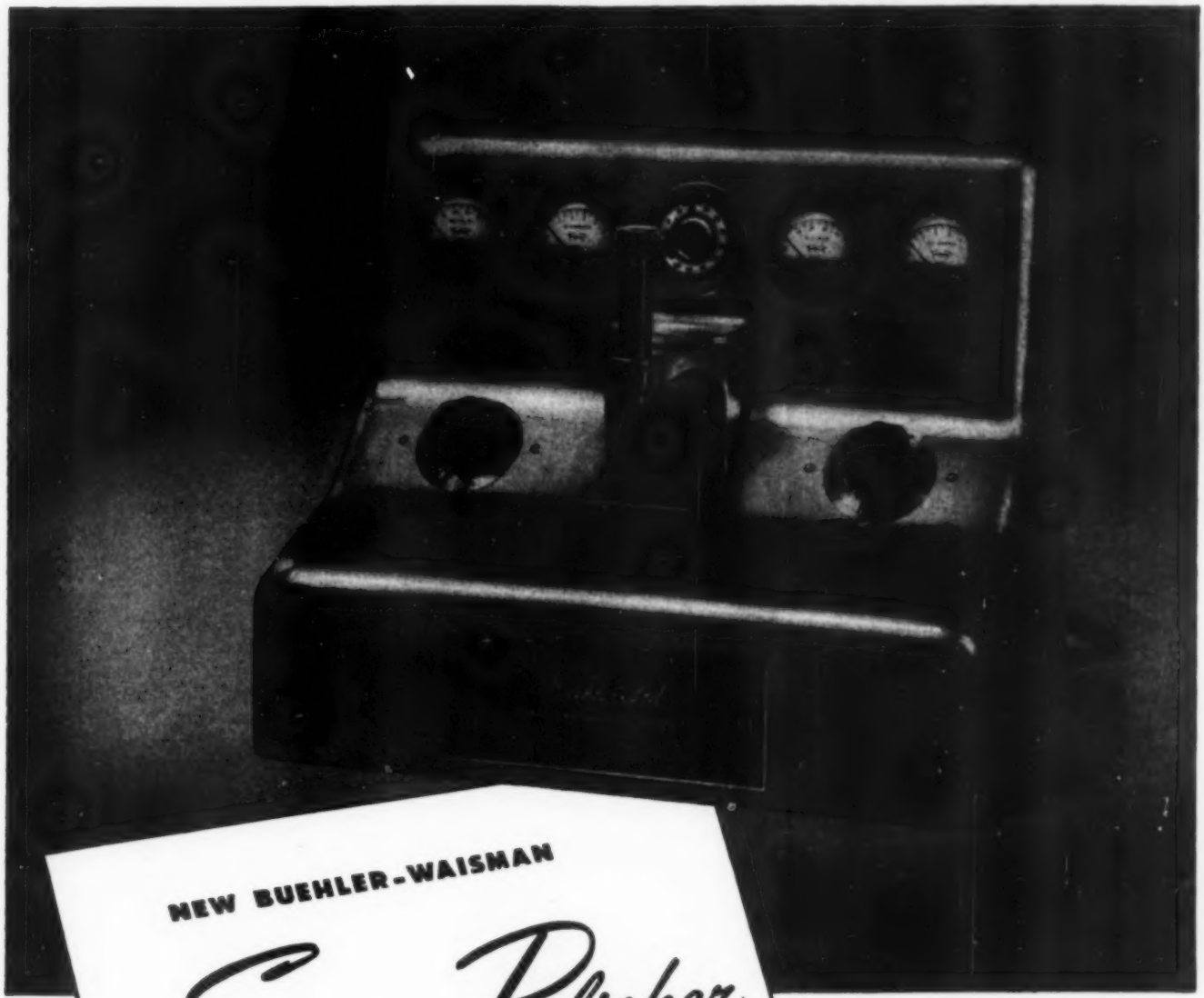
hot-dip GALVANIZING



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Hot Shortness of Al-Si Alloys

(From p. 1028) increased sharply with the addition of silicon to a maximum at 0.7% Si, and then decreased rather less rapidly, reaching zero at about 3% Si. With greater percentages of silicon, no cracking was observed. Cracks were almost invariably along the grain boundaries.

In the welding experiments, carried out on sheet under conditions of restraint, the maximum amount of cracking was found to occur at about 0.8% Si. The severity of cracking then decreased to a low value as before. All observed cracks were intergranular.

Good agreement between the results of the two tests suggests that the cracking process is similar. It was shown that the cracking occurred above 930° F.

The practical conclusion is that pure aluminum, containing approximately 0.2% Fe, which is to be welded into complex structures should contain less than 0.25% Si. The alloys within the range 0.25 to 3% Si appear to be of limited value for casting and welding, but those containing more than 3% Si should have good properties from the point of view of freedom from cracking. The greatest degree of hot shortness occurs in alloys containing 0.7 to 0.8% Si.

According to a modification of Verö's theory, the degree of hot shortness should reach a maximum at the composition coincident with the limit of solid solubility at the eutectic temperature. Experimental curves indicate that the effective solid solubility limit of silicon in aluminum under the conditions of the experiments was about 0.7 to 0.8%. At the solidus, there is a sudden increase in ductility, and it can be assumed that below this point hot cracking is no longer possible. Thus, it would be expected that the aluminum-silicon alloys would be most susceptible to hot cracking at or immediately above the solidus temperature, for at this point the amount of movement which can be accommodated by the material without cracking is at a minimum.

Aluminum-silicon alloys have a pronounced lack of ductility between the solidus and the temperature of losing strength. This temperature interval, which has been termed the "hot short temperature range", is greatest at the composition *(Cont. on p. 1032)*

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Hot Shortness of Al-Si Alloys

(Starts p. 1028) coinciding with the limit of solid solubility. The severity of cracking will depend on the amount of contraction while the hottest part of the weld or casting passes through the hot short range. Contrary to Verö, it appears that cracking is possible and will frequently occur even though the residual liquid solidifies at constant temperature. Thus, the hot cracking of castings or welds in aluminum-silicon alloys can be accounted for theoretically by one principal factor — the extent of the hot short temperature range. This single factor, of course, incorporates in modified form the conceptions of freezing range and eutectic index which had previously been advanced to explain the phenomenon of hot shortness.

Foundry Control by Measuring Density*

POROSITY VALUE determined from density measurements forms a useful method of quality control, provided the standard density is representative of the composition tested, the observed density is measured accurately, and the relation between porosity and the particular properties which have to be controlled has been determined for the type of casting concerned.

The per cent porosity is taken as

$$100 \times \frac{\text{S.D.} - \text{O.D.}}{\text{S.D.}},$$

where S.D. is the standard density and O.D. is the observed density. The apparent density (weight in air minus the weight in water divided by the weight in air) at the temperature of the experiment is generally used for the "observed density". Probably the most satisfactory value for standard density is determined from the lattice parameters of the alloy constituents. The available X-ray values, however, are difficult to apply to commercial compositions. An alternative standard is the maximum apparent cast density as determined on small chill-cast test bars. Within the limits of normal experimental error, the maximum cast density of tin bronzes does not vary appreciably with the tin content or with structural variations. The effect of phosphorus, zinc and lead in tin bronze may be calculated with adequate accuracy from:

$$\text{Maximum cast density} = 8.88 - 0.016\%\ \text{P} - 0.02\%\ \text{Zn} + 0.025\%\ \text{Pb}$$

Arsenic or traces of aluminum, manganese and silicon may seriously reduce the maximum cast density. Other impurities, such as antimony, iron, bismuth and lead, have only a very slight effect in amounts up to 0.5%.

The weighing should be accurate to within 0.0001 of the total weight of the sample for an accuracy of 0.01 g. per cc. The weight of the suspension should be small in relation to the sample weight. An additional precaution is to use a suspension wire of a metal with a density about equal to that of the sample. Retention of air bubbles is largely avoided by the use of a wetting agent.

Density measurements reflect only the total volume of cavities. The importance of the calculated porosity must therefore be assessed in respect to the form and distribution of the cavities. Four major types of cavities affect the density and other properties in differing degrees. Spherical cavities caused by mechanically entrapped gases may have a severe effect on density but do not cause a marked deterioration of the mechanical properties. Trumpet-shaped cavities are frequently associated with local segregation. Density alone does not form a safe guide to such cavities, but their presence is often indicated by surface exudations. Angular cavities at grain junctions, caused by inefficient feeding, affect both density and mechanical properties. Fine intercrystalline fissures have only a slight effect on the density but are very detrimental to strength and are the chief cause of leakage.

For castings of similar shape, approximate linear relationships of the form $T = a - bP$, where T is the tensile strength or elongation, and P is the per cent porosity, exist between porosity and tensile properties. Such relationships may give a better guide to the tensile properties of castings than can be obtained from testing small coupons.

*Abstracted from "Density Measurements", by W. T. Pell-Walpole. *Metal Industry*, V. 70, Feb. 14, 1947, p. 123 to 125.

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It is up to the worker with metals to follow what's new as well as to understand what's old, and this book helps the reader to do just that. General principles and behavior that are common to many metals are summarized. Knowledge of the alloys of one metal frequently applies to those of another, and as Prof. Mason says, "it won't hurt any 'brass' man to learn a little about alloys that aren't yellow, particularly since metals are so often in competition with each other."

TABLE OF CONTENTS

Nature and formation of metal crystals — extractive metallurgy; crystalline nature of metals; dendritic and columnar structures in cast metals . . . Alloys as solid solutions — properties of solid solutions; freezing of solid solution alloys; coring; limits of solid solubility . . . Working and annealing of metals — elastic and plastic deformation; work hardening, fatigue and creep; annealing and recrystallization . . . Unmixing of solid and liquid solutions — age or precipitation hardening; aluminum alloys; eutectic alloys; structural composition from phase diagrams . . . Solid solution in brasses and bronzes — "Alpha" alloys; intermetallic compounds; geometrical precipitation; peritectic reactions . . . Iron and steel — polymorphic transformations; eutectoids; structural changes with temperature . . . Heat treatment of steels. Cast Irons — quenching and tempering; alloy steels; white, malleable, and gray cast irons . . . Corrosion — electrochemical reactions; couple action; hydrogen ions and oxygen in corrosion.

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IT IS difficult to use normal oxy-acetylene cutting on stainless steel, mainly because of the high chromium content. A number of means have been used in the past to overcome the refractory effect of the chromium oxide but the results have not been satisfactory.

Powder scarfing now does the conditioning that previously could be carried out only by grinding or chipping at a slower pace, thus short-circuiting the former mechanical methods of nibbling, cold sawing and other relatively slow machining operations.

A fine, iron-rich powder is the basis of the new method. In cutting operations, this powder is usually blown into the oxygen stream from outside the nozzle preheat flame, while in scarfing, the powder is drawn into the oxygen stream within the nozzle. In both, the powder is heated to the ignition temperature by the oxy-acetylene preheat flame, at which time it burns in the oxygen stream. The heat generated by this reaction starts the cut without preheating. As soon as the cut progresses into the material, the refractory oxides are continuously removed by a combination melting and fluxing action. The required apparatus is relatively simple and inexpensive.

In the steel mill, the process is applied principally in the conditioning of surfaces of stainless steel blooms and ingots, and in cutting sections from 3 to 26 in. thick. Hand scarfing operations on stainless are carried out at a speed approximately one fourth to one third the speed used on carbon steel with equivalent oxygen flow. The cutting of stainless can be done at speeds comparable to those for the equivalent thickness of carbon steel, although the surface is rougher. The quality of the rolled product from a scarfed billet is equal to or better than that of a ground billet. The method has also found valuable use in the removal of hot tops from ingots.

Any badly cracked edges of slabs can be trimmed off quickly, while relatively thin plate can be cut to size prior to rolling into clad plate. Certain scrapping operations present rather *(Cont. on p. 1036)*

*Abstracted from "Powder Cutting and Scarfing of Oxidation Resistant Materials", by D. H. Fleming, Jr. *Journal*, American Welding Society, V. 26, March 1947, p. 201 to 208.

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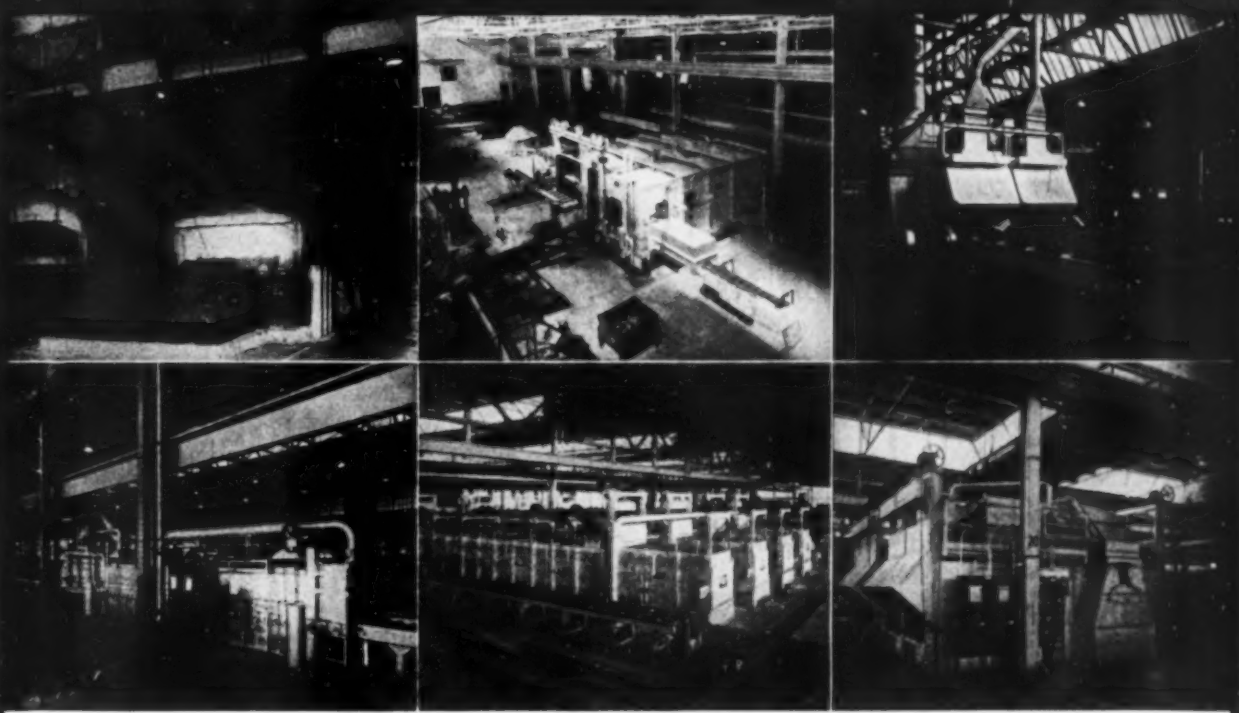

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Powder Cutting and Scarfing

(From p. 1034) attractive possibilities for the powder cutting process. The cost of this application is approximately equivalent to that of good lancing practice.

In the foundry, the process has found considerable application in the removal of stainless steel risers which heretofore had been melted off by the much slower carbon or metallic arc method. The cutting speed is almost equal to that obtained on carbon steel risers. Moreover, rigid cleaning of adhering sand prior to riser removal is not necessary. The fabricator will find the process particularly useful as he can cut or fabricate sections heavier than the capacity of his shearing equipment. It will likewise speed up shape cutting, previously done with band saws.

If the stainless steel is hardenable, hardening of the cut surface will result. Cracking of the hardened layer can be prevented by the same procedures used for low-alloy steel, such as mild preheating. With unstabilized austenitic grades, a thin layer will show carbide precipitation and should be removed by a light grinding cut.

In addition to stainless steel, certain specialized applications of the method exist in the field of cast iron, high alloys and nonferrous materials, including Hastelloy, nickel and nickel-base alloys.

Length Changes Under Torsion*

THIS WORK was initiated to provide a practical check of a construction proposed by Nadai whereby the curve of shear stress versus strain could be obtained for a given metal from an analysis of the torque-twist curves made from solid bars of that metal. Tests were conducted by twisting solid bars and hollow tubes of metal and the corresponding curves of shear stress versus strain compared. As the shear stress is essentially uniform over the wall of the tube the stress-strain curve obtained from the tube torque-twist curve formed the criterion to compare the curve of shear stress versus strain, derived from the torque-twist curve of the solid bar by using Nadai's construction. This construction was found to be valid, since the curves of shear stress versus strain obtained from the solid bars were essentially the same as those obtained from the tubes.

During the course of the test work it was observed that the tubes had reduced in diameter slightly, implying a change in dimension that was not in accordance with any known theory. (It had always been assumed in the past that the length, thickness and diametral dimensions of a tube under pure torsion remained constant.)

To investigate this matter a special torsion jig was constructed embodying ball bearing grips designed to permit complete freedom to the test piece to elongate or contract along its length while being subjected to torsion stress. The jig was used to obtain the relationship between axial strain and torsion strain on seven different metals, as follows: 70-30 brass,

(Continued on p. 1038)

*Abstracted from "Length Changes in Metals Under Torsional Overstrain", by H. W. Swift. *Engineering*, April 4, 1947, p. 253 to 257.

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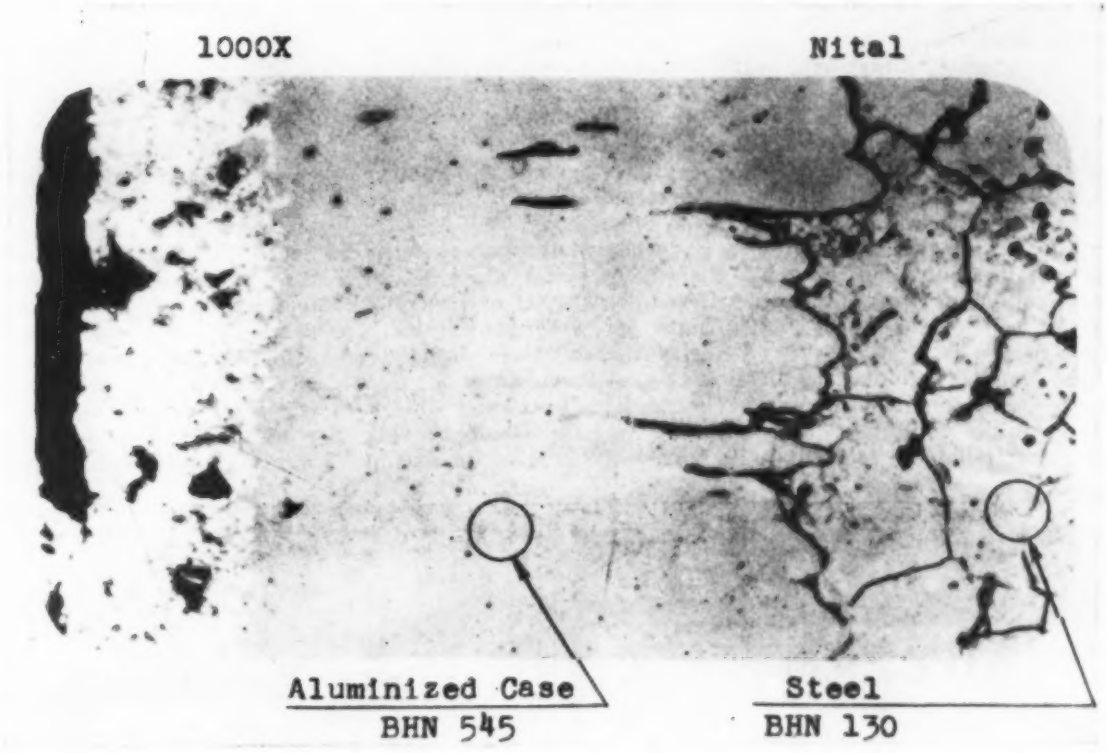

The aluminum-iron alloy resulting from this method not only has high hardness, but also has high resistance to corrosion. Thus, resistance to corrosion with this process does not depend upon the external layer of aluminum alone.

The effect of subsequent heating appears to improve, rather than impair, the bond between aluminum and steel. Moreover, steel which has been aluminum coated by this process has been successfully employed in applications involving temperatures up to 1800° F. — gas generators, charcoal burners, etc.

Equipment to produce this aluminum coating is neither expensive to procure nor costly to operate. It can be either batch (as for small quantity fabricated parts) or continuous (as for wire, rod, strip, sheet, or fabricated parts). It has a short, though not critical, time cycle. It is recommended for your further investigation. **Upton Electric Furnace Division, 7450 Melville at Green, Detroit 17, Michigan.**

Length Changes

(Continued from p. 1036)

stainless steel, aluminum, cupronickel, copper, mild steel and 0.5% carbon steel.

From the plot showing shear strain versus extension for these metals in the indicated tests, it is apparent that all the metals exhibited a marked tendency to elongate under plastic shear strain, 70-30 brass and stainless steel showing this most pronouncedly and about equal in degree. The elongation observed was accompanied by a corresponding reduction in area, without measurable change in volume of the test piece.

A series of tests was conducted with 70-30 brass wherein the direction of twisting was reversed at various stages of the test, and it was found that the extension effect is not reversible in any true sense, because the metal extends regardless of the direction of twist. At low angles of twist the rate of extension per degree is much less than at high amounts of plastic shear strain. Annealing returns the metal to its initial condition.

A lead bar was tested and found to contract with increasing shear strain beyond tan $\phi = 2$. A test repeated on the same bar after remachining and 24 hr. rest gave a practically identical curve of shear strain versus contraction up to shear strain of tan $\phi = 5$.

Since the effect noted of axial extension is greatest in the metals which "strain harden", actually reversing from extension to contraction in the case of lead, Professor Swift advances a hypothesis involving crystal rotation in an effort to explain the phenomena observed. He feels that in a random distribution of crystal aggregates, those crystals having their slip planes unfavorably oriented with respect to the direction of stressing will be forced to rotate through the impingement of adjacent crystals having slip planes more favorably oriented to the direction of stressing. This hypothesis is developed through sketches of simplified crystal diagrams in an effort to show that crystal rotation must occur if any length change is to result from the application of pure shear stress.

The author feels that metals consisting of body-centered cubes will have less tendency to extend under shear than those metals of the face-centered cubic lattice. As the body-centered cubes have more planes of possible slip, plastic shear strain can occur by slip for the most part with little crystal rotation, whereas in the face-centered cubic structure a greater number of crystals will have been forced to adjust themselves to the changing geometry of strain by rotation, for a given shear strain, and therefore in metals of the latter type a greater tendency for extension will be noted. Similarly, for metals exhibiting strong strain hardening tendencies, an increasing amount of the strain adjustment must be taken by crystal rotation, as the resistance to slip on glide planes increases with strain.

This investigation and its conclusions appears to be limited to metals in the plastic condition, and there seems to be no reason to doubt that in the elastic region there is no tendency for bars under torsional stress to extend or contract. Indeed under small amounts of plastic shear strain, the extensile effect is quite small. In stainless steel, for example, shear strain must equal tan $\phi = 0.4$ before there was any extension measured.

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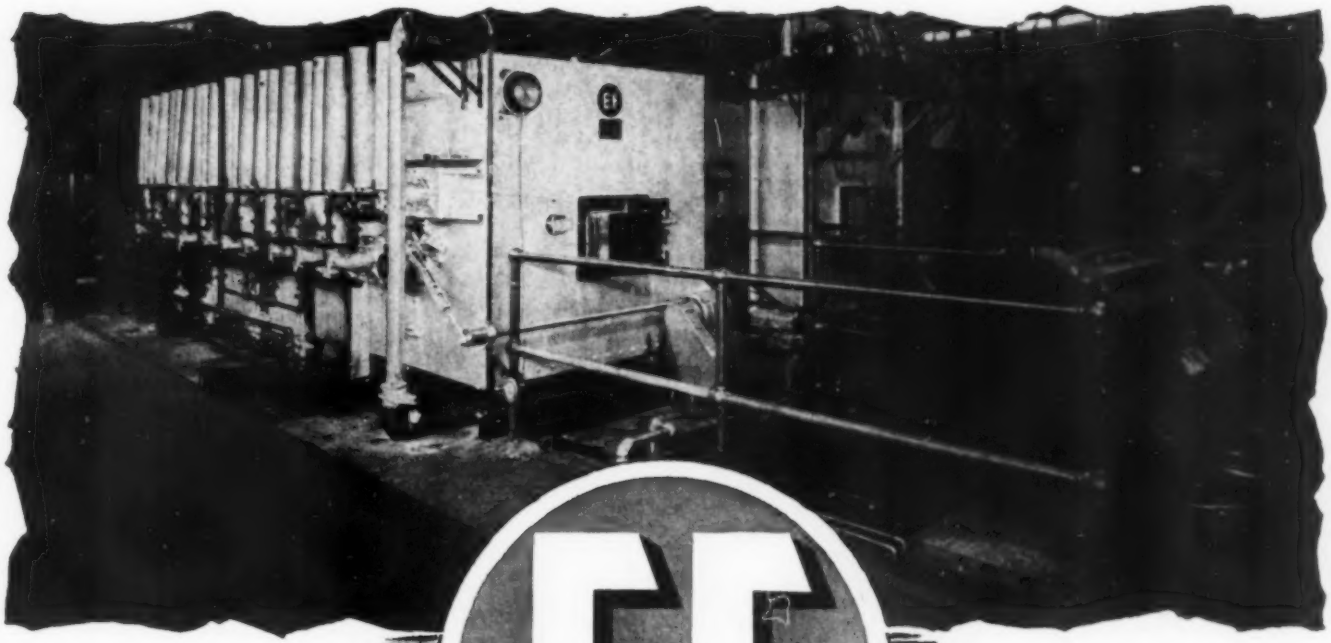

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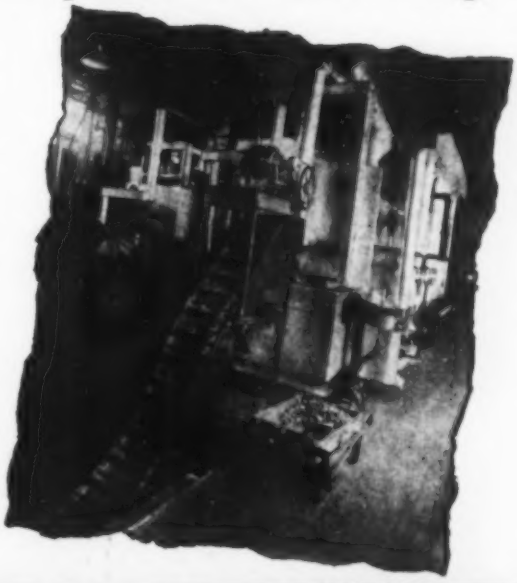

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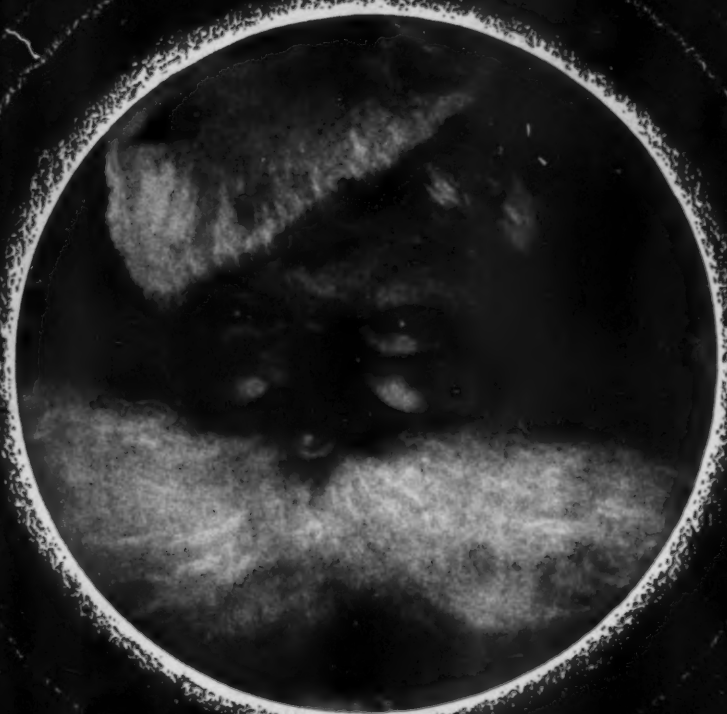

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